Structural Coupling on Creative Interfaces

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ABSTRACT
We describe how self-production systems theory can be applied in the design of new creative interfaces. By modeling the interface as an organizationally closed system, we can support creative agency while still allowing collaboration with the user. Although in this approach the interactor no longer solely determines the output, both the user and interface can become structurally coupled, achieving a balanced interaction. We discuss our theoretical motivations and describe an initial attempt in the domain of human-machine collaborative painting.

Author Keywords
Interactive art, robotic, collaboration, dynamical system.

ACM Classification Keywords
J.5 Computer Applications: Arts and Humanities; I.2.9 Robotics: manipulators; I.6.8 Image Processing: Simulation and Modeling.

INTRODUCTION
Creativity is an important underlying element in innovation, design, science and art. However, understanding what it is and how it develops continues to be a challenging problem. In art, it can be seen as arising from the individual, the process, as a property of artistic artifact, or even as a result of the environment [18].

Despite those many different views, good tools can help in the creative process by freeing cognitive resources or by sparking new ideas. This motivation has prompted several studies to understand the best way to design such tools [9][20][25][21][3][17]. Shneiderman et al. [22], for example, propose a set of design principles focusing on features such as support for easy exploration, rapid experimentation, and making sure that new combinations can happen by chance. However, different views on creativity will lead to different prescriptions on how to better support it.

In this paper, we explore the view of creativity as a result of agency [19] and how it can be used to enhance artistic work. In particular, we discuss how to design a system endowed with creative agency that can also act as a bodily extension of the user for creative tasks. We use the term Creative Interface to refer both to the creative goal of the interface and the creative aspects embedded in it.

Our approach is inspired by the concept of self-production systems, introduced by Maturana and Varella [13]. Thus, the collaboration that arises between the user and the interface is different from the traditional role attempted by artificial intelligence partners [12] [2]. Rather than posing as an equally competent partner, our goal was to add a new capability to the interactor. From the interaction perspective, it serves as a new found limb (albeit one with some will). The interaction, hence, would happen without the need for a domain level representation [16].

To explore this concept, we developed the interactive robotic installation *Better Hands* (2017). It is composed by a robotic arm with a brush and a tablet. The interactor wears a wireless armband that senses the electric activity of the muscles and the orientation of the arm using an inertial measurement unity. The tablet runs a control system that can be perturbed by the input from the armband and generate stroke patterns and send motor commands to the arm (Figure 1).

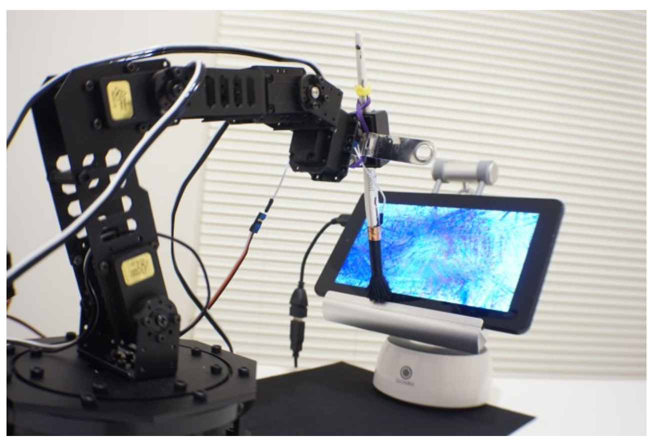

Figure 1 – Better Hands Installation

STRUCTURALY COUPLED INTERFACES
Our use of structural coupling to develop creative interfaces is based on the cognitive creativity thesis. In summary, it states that creativity results from cognitive acts or is at least enabled by it. Davis et al. [7] present a theory for creativity support built on the concepts of *embodied*, *distributed* and *situated* creativity.

C&C '17, June 27-30, 2017, Singapore, Singapore

ACM ISBN 978-1-4503-4403-6/17/06.
http://dx.doi.org/10.1145/3059454.3059508

The *embodied* argument claims that creative acts are facilitated by the existence of the body in the world, while the *distributed* recognize the aid of external symbols and objects in the creative process. The *situated* argument captures creativity as an activity in-the-world.

For Varela and Maturana, what we understand as a cognitive behavior is the set of activities that organisms undertake to maintain their existence [13]. Despite structural changes, they are able to sustain their organization through the continuous production of its own components. These systems are called self-producing or *autopoietic* systems.

Autopoietic systems are organizationally closed, meaning that all internal states led to other internal states. There is no direct input or output. The environment, however, can trigger changes in the structure of the system, to which the system responds by adaptation. A single cell is autopoietic on the molecular level, while a neuron system is organizationally closed. Closed systems can interact with each other through structural coupling [14].

Autopoiesis has been applied to explain a variety of non-biological systems, such as social and psychological systems. In the realm of creativity, Takashi Iba [10] proposes an autopoietic model, where the basic element is a "discovery". Each discovery is produced based on previous discoveries, leading to a closed organization. This model, however, does not help to explain how actual artifacts of a creative process come to exist.

In this work we propose another approach, which makes possible to understand how autopoiesis can be applied to creative production. The key is to conceptualize a system where each state (production) has a defined meaning within the application domain. In *Better Hands*, the system states correspond to different brush strokes. They are defined by a position on the canvas and additional parameters that define the shape of the marking / stroke and color. This forms the "stroke space", a closed system that can evolve even under interference (Figure 2).

The sequence of states constitutes an orbit that can be understood as the result of the evolution of a dynamical system over time. Dynamical systems are often used to model mechanical or biological process and can be discrete or continuous. In robotics it has been used to bind sensors and actuators while considering the physical dynamics of the robot [6]. Here we use it to model the agency of the system within the painting domain.

Once a semantic mapping is found between the domain and system states, we need to make sure that the system can keep its organization over multiple iterations and will not "die" when coupled with another system/user. The most straightforward approach is to use dynamical systems that contain a geometric or a strange attractor. This ensures that the orbit will evolve in a stable way if left alone. In addition, any perturbation introduced by an external system will remain within the design boundaries. In our application, the system will evolve along a new trajectory, which is defined by the dynamical system itself, as a result of its previous history and the user's input.

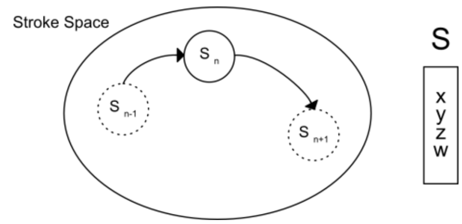

Figure 2 - Self-production system for a painting. Each stroke is defined by four parameters (explained in the next section). The boundary of the system is defined by the regenerative process that is produced by the sequence of strokes.

IMPLEMENTATION

The *Better Hands* installation consists of a dynamical system core embodied into a robotic arm and tablet. This gives it the ability to sense and act in the world. The robotic arm used in the installation is a commercial five joint arm, driven by servo motors [26]. The gripper was modified to hold a small brush. To make it capable to activate the capacitive touch screen, it was painted with conductive ink and connected to the robot electrical ground. The servos are driven by an Arduino [27] board, which receives commands from the tablet through the serial over USB. Since tablets usually act as peripherals, we used an USB-to-Go cable to control the arm. The tablet runs Android and connects to the Myo [28] armband through Bluetooth 4.0, using the library developed for the Uniklinik RWTH Aachen mHealth project [11]. We use EMG stream that comes pre-filtered from the armband to avoid interference from external electromagnetic fields.

The interaction between the robot and the interactor is established through two coupled loops (Figure 3). The first loop directly links the interactor and his arm. The feedback is the visual perception of the painting process (a). The second loop links the machine intention with the robotic body through the USB. The feedback is composed by the touch events received by the robot (b). Both loops are coupled when the robot senses the interactor arm through the armband and when the human sees the robotic arm (blue arrows).

The installation software is composed by three main modules: the Dynamics module, the Brush Pattern module, and the Motor Control module (Figure 4). The Dynamics module couples the external stimuli (from the interactor's arm) and modulates the update of state by presence of *self-stimuli* (from the touchscreen). The current system variables are reflected on the Brush and Motor modules. The eight channels from the Myo's EMG sensors are combined into two signals before entering the Dynamics module. The yaw and pitch angles from the IMU are used directly to control the brush position but are collapsed into a single variable in the dynamical system.

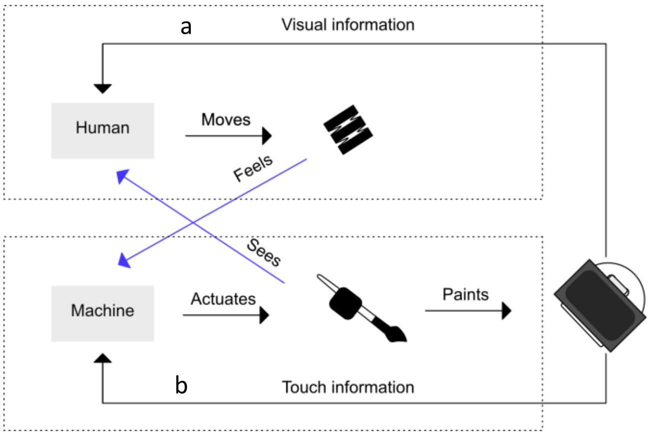

Figure 3 – Coupled interaction loops. Both human and machine run two proper loops. The two loops are coupled as shown by the blue arrows.

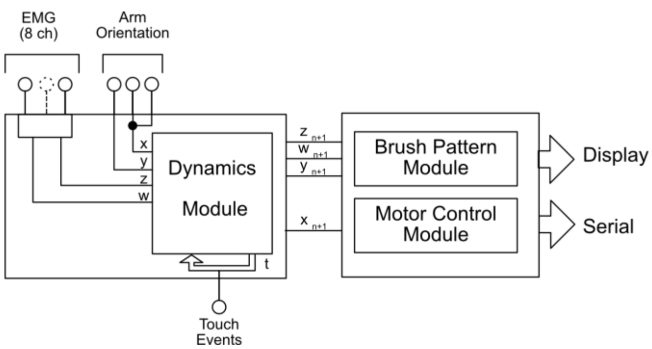

Figure 4 – Architectural overview. The interactor input perturbs the dynamic module. The variables are passed to generate the brush patterns and actuate the robotic arm.

The Brush Module creates brushes by drawing over the points of temporary attractors generated by an iterated function system (IFS). The system is composed by three 2D affine transformations, giving a total of 18 coefficients. The coefficients were condensed into three parameters, which encode the distance between the transformations, relative rotation and scale. The IFS is drawn by selecting a transformation randomly in each interaction step (Chaos game) [1]. Following Sprott [24] suggestion, we also adjust the selection probability to be proportional to the *jacobian* of each map, to obtain a better coverage.

Since we want to draw the strokes under the brush position, we need to determine the center of the attractor. Instead of finding the center of the convex hull (which would add additional overhead) we just run the system for a few iterations and use the average 2D position as the center. The final rendering of the brush is drawn using lines and points. Lines are used to connect points in close proximity while points are used for the rest. In this way, smaller attractors have more lines and larger ones are drawn as scattered points. Figure 5 depicts some sample brush patterns.

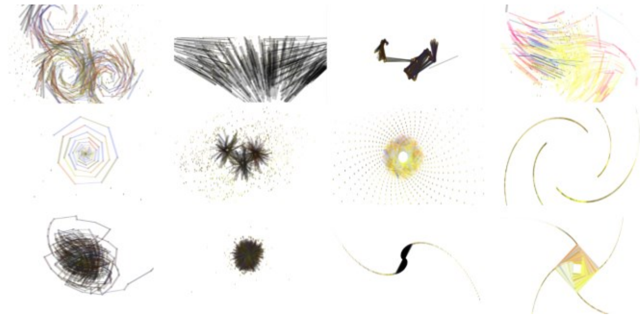

Figure 5 – Sample brush patterns generated by the Brush Pattern module

The Dynamics model holds the dynamical system that performs the evolution of the strokes through time. It is a four-dimensional Hamiltonian system using sines and cosines. The solutions to these systems are chaotic but do not form an attractor. Thus, orbits do not collapse as the system evolves from an initial condition [23]. This makes them even more appropriate for our system: they have the necessary plasticity and yet are still determined by a structure. We selected an attractor with a good coverage of the space and variability from Sprott [24]. The equations are:

$$x_{n+1} = a_1 + [x + a_2 \sin(a_3 y + a_4)] \cos a_0 + y \sin a_0$$
$$y_{n+1} = a_5 - [x + a_2 \sin(a_3 y + a_4)] \sin \alpha a_0 + y \cos a_0$$
$$z_{n+1} = a_1 + a_6(xy) \cos \alpha + a_7 w \cos \alpha \qquad \text{EQ.1}$$
$$w_{n+1} = a_1 + xy \sin \alpha - z \sin \alpha$$

Even though the general shape is defined by the map, constants can alter the specific shape of the attractor. They were adjusted to yield an interesting structure. Figure 6 shows planar projections of the map.

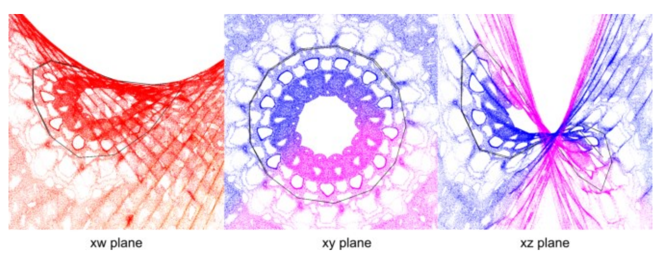

Figure 6 – Planar projections of the dynamical system from EQ.1. Black lines show the first 20 steps of an orbit with initial values: $x_0 = y_0 = z_0 = w_0 = 0.05$.

The final paintings (Figure 7) reflect a combination of user intent and system reaction to those changes. As the orbit through the space state is perturbed it includes elements which are on intermediate points. The feedback of the touch events prevent the dynamical system to go forward so the interactor has more control over the process.

DISCUSSION AND RELATED WORK

Most painter systems developed so far fall into a few categories regarding their goals: a) being able to reproduce an existing work or painting style, b) enable remote painting (telerobotics) or c) achieve higher aesthetic control (improved control, mixing of colors, etc.). For example, although Brain Painting [8] uses a brain-computer sensor to control a robotic painting arm, there is no agency in the interface, which simply maps input to output. Other robotic painters like the ones designed by Patrick Tresset[i] are autonomous and although the results are aesthetically interesting, no collaboration happens between human and machine.

Our work is more similar in intention to Colton's Painting Fool [4] and Cohen's AARON [15] artificial intelligence painters. Painting Fool simulates cognitive behaviours to express ideas through scene composition, while AARON is capable of drawing original figurative scenes containing people and other objects. Both show a good degree of creative agency, obtained through curation and/or training. However, the collaboration only happens during those phases. The approach used on *Better Hands* was to model an autopoietic process and use it to couple with the interactor, obtaining a realtime result influenced by both.

Corness and Schiphorst [5] describe Ariel, a computer agent uses breathing patterns to help communicate upcoming musical gestures to performers. The objective was to use embodied cues, which could be picked up in a subconscious level by the performers. The musical 'decisions' are defined by probability distribution functions, weighted by events captured by a computer vision system. In our work, we use a dynamical model that allows response variety while also considering the past. The interaction quality is also different: while Ariel was designed to be present as a partner to whom you can adapt, we designed *Better Hands* to be and feel like a part of the body that you can influence.

In our experience, interactors had no problem in using the system to produce paintings. Initially, interactors seem to rely only on the orientation of the arm since it is easiest to understand. Hand gestures came later, as they try to explore the new possibilities for their painting. Some users demonstrated enjoyment in being able to control the robotic arm with only remote gestures. We also noticed that users learn to adapt to the pace of the robotic arm, which takes a few seconds to draw each stroke.

Modeling the painting process as an autopoietic system allowed us to think more deeply about the role of interaction on the creative process. How much of the future action is determined by the previous one? In our work the original plans of machine and iterator does not survive long as one need to adapt to the other. Does the structural coupling with our tools necessarily collapse the space of possibilities? The framework suggests that it is so. However it does not mean that tools need to stay under control during the whole session. As two colleagues discussing ideas, contributions are added along the way, but in different times. As in any effective collaboration individual contributions must consider the prior history and the unique perspectives of each one.

A difficulty remains in finding appropriate mappings between solutions of a dynamical system and the desired outputs. In our case the mapping goes straight from the dynamical system to the Brush and Motor modules. To ensure a more pleasant experience, the iterator can explicitly indicate the area of the canvas to be painted. We also sub-modeled the system by using only four dimensions. Since not every state needs to be externalized, more internal states would allow more freedom to choose the basic shape of the attractor and still have sensible mappings for the output.

We also noticed that although the use of a robotic arm increased the sense of presence and embodiment of the system, the hardware we used lacked precision and accuracy. This forced the use of larger strokes, which reduced the sense of user control. A finer position control would allow the creation of more directed, less abstract paintings.

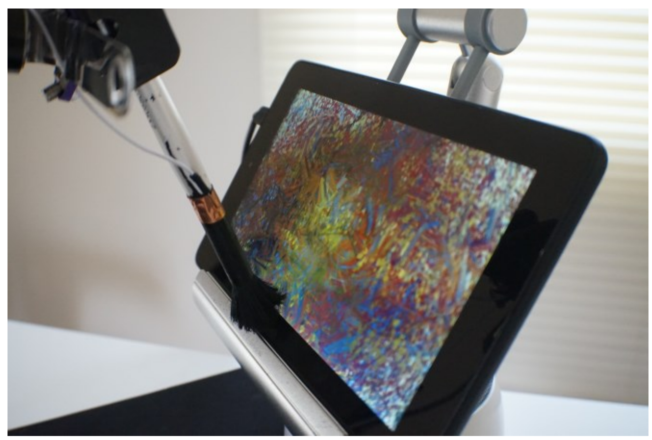

Figure 7 – Output of the installation Better Hands

CONCLUSION AND FUTURE WORK

This paper presented an approach to use self-production systems to inject agency into creative interfaces. We described the design of a robotic painting system, *Better Hands*, which is realized as a robotic arm and tablet. In the future we plan to collect more information on how different users interact and experience the system. We also plan to investigate how different parameters influence the perception of painting. Finally we intend to explore new opportunities to apply dynamical systems to support and investigate creative processes.

ACKNOWLEDGMENTS

The authors would like the Virginia Tech CS Department, FAPEMIG, CNPq, PROPPG/UEMG and ACM for their support.

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