Describing systems for the exploration of tangible and spatial computer interaction

Final year project in Creative Computing BSc (Hons)

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Thanks to my family, Florent, Chudleigh dwellers, Jamie ...

Abstract

Presented here is a specification for experimental approaches to computer interaction based on spatial and tangible methods. The report describes an prototypical implementation of a base system for computer interaction using physical objects on a surface. A theoretical API for such a system and similar systems is proposed. This utilises computer vision techniques to analyse a surface to track objects and the projection of graphics onto the space creating a feedback system for interaction. An attempt to gather together literature and examples of such existing systems is made. The fundamental principle of the interaction system here described is summarised in the sentence below:

> Physical objects on an *action surface* have interactive properties, each object is both a sensor and actuator.

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Introduction

1.1 Project aims

- open source project for tangible interaction
- Prototypical
- ethnomethodological frameworks for evaluation

Chapter 2

Background

The motivation for this project stems in part from a feeling of frustration in how working on computers can often be a constricted affair and a pondering over how we might expand the *keyboard-mouse-monitor* model to improve the utility of computers regarding our physical health, wellbeing and perceptive abilities. How might a spatial, haptic and tangible environment for interaction create an improved space for working and thinking with computers as well with our physical health [Twenge, 2020]? How might such an environment fundamentally augment our cognitive capabilities; memory and learning as well as creativity itself?

2.1 Definitions

1. HCI - Human Computer Interaction
2. KMM - keyboard-mouse-monitor model
3. Exocortex -

2.2 *Exocortices* and augmented cognition

I started off looking at *Exocortices* and other personal archiving systems. Systems that allow the user to externalise thought and memory. This could be via simply storing and organising work and ideas efficiently and methodically or unifying many tasks or different workflows into a singular interface.
Org mode is a good example of such a system. Org mode is a "computing environment for authoring mixed natural and computer language documents" [Schulte et al., 2012]. It is designed for taking notes, producing documents and organising and runs inside of the text editor, Emacs. It has the ability to export to different formats such as HTML, LaTeX and supports "outlining, note-taking, hyperlinks, spreadsheets, to-do lists, project planning, GTD" as well as literate programming, all in plain-text [Schulte et al., 2012] (it is incidentally what this document is produced with).

Another point of reference when I was looking at externalised 'artificial information-processing systems' was Devine Lu Linvega's Exocortex XXIIV – nataniev. *XXIIV* is a personal archive and log with documentation of Linvega's personal tools and artworks. The site has gone through some changes since I first came across it. Originally a static, javascript and lisp based website with diaries, blog type posts and categorised personal logs. It is now somewhat stripped back in style and has been rewritten in C (C99) [Linvega, html].

Both these two systems have their own specific use-cases, *Org-mode*; in academia and science and *XXIIV*; an experimental personal archive. They both utilise the contemporary and prevailing *keyboard-mouse-monitor* paradigm of computer interaction but push the boundaries of cognition in this medium, particularly regarding memory and productivity. These two projects were a birth point in thinking about how software systems can be augment thought and improve learning ability and computer productivity.

Information visualization is a tool for the augmenting and externalising cognition that most take for granted. Utilising visualisation for tasks memory tasks by organising attention and concept mapping are useful ways to increase our abilities [Ware, 2013]. Scientist Michael Nielsen also offers some approaches to increasing long term memory through the use of simple flash card software that orders things you want to memorise by how well you know them. He suggests this and the process of creating question / answer flashcards of an idea you want to remember improves memory capacity, understanding and our ability to do deep readings of a subject [Nielsen, html, Carter and Nielsen, 2017].

2.3 A virtual exploration of a 'dynamic land'

Another original and critical point of reference was *Dynamicland*, a research project in Oakland, USA. The aim of the project is to implement a new more powerful and accessible model of computing.

> In Oakland, we built the first full-scale realization of the vision, inviting thousands of people into our space to collaborate. Together, these artists, scientists, teachers, students, programmers, and non-programmers created hundreds of projects that would have been impossible anywhere else. – Dynamicland.org

Dynamicland is a communal computer where the building is the computer (ENIAC). Programs are embodied in the room on pieces of colour-coded paper. The programs are recognised via the codes and their code, stored in a database is then run, it can also *read* code using OCR but generally the code is there symbolically. Projectors on the ceiling transform the paper and workbenches into whatever the programmer decides. This relatively simple model makes for an exciting new ecosystem for collaborative computing and expressive programming. Victor highlights his ideas for the progression of computing and interaction in a series of talks (available online) and on his website. In his talk "Seeing Spaces" he talks of a new kind of maker-space which allow makers to see across time and possibilities. *Dynamicland* seeks to offer a computational medium which allows for full use of the human senses;

a more humane representation of thought [Victor and Kay, dorg].

Figure 2.1: RealtalkOS, the operating system of *Dynamicland*

DL was a major inspiration for the main technical model for this project, an *augmented* workspace either on the floor or a table which is projected onto. A camera/s pointing down onto the projection space is the sensor for detecting interaction, with the projector as the actuator. This base model can be seen in Figures 2.3 and 4.2.

2.4 Paper programs

Looking to find some of the code for *Dynamicland* and a more detailed specification of **DL** I stumbled across *Paper Programs* (PP) (*Dynamicland* has an 'open-source model', but it is only open if you can visit it physically as the source code is physically in the space). *Paper Programs* (PP) is a browser-based partial clone of *Dynamicland*. PP takes one element of dynamicland, i.e. the representation of computer programs in a spatial environment, on pieces of paper. Programs are written in Javascript and stored in a Postgresql database. This idea of 'physicalizing' some method or element of the computer and allowing the direct haptic manipulation of it has further inspired this project.

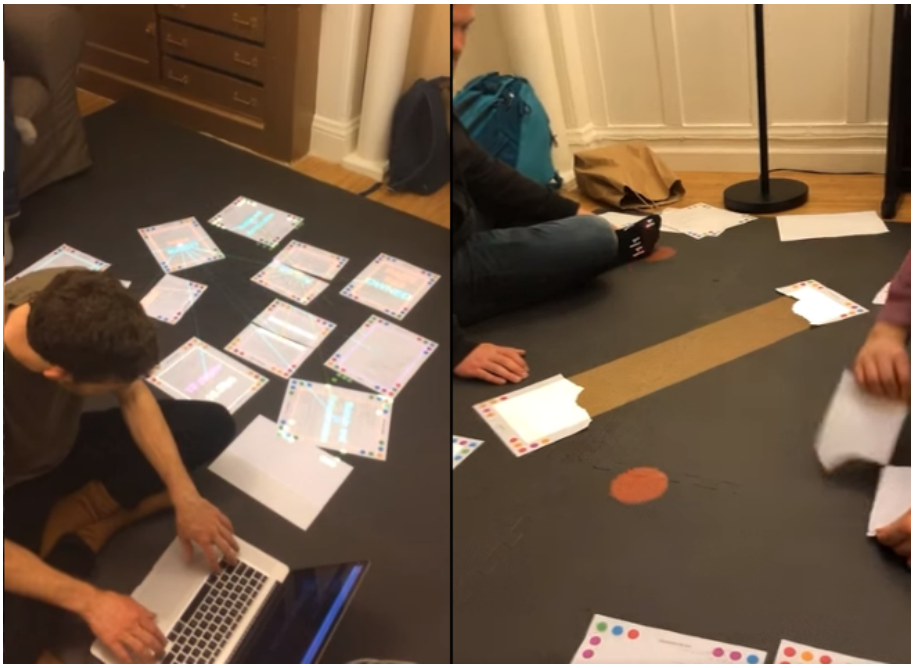

Figure 2.2: *Paperprograms* in action

PP aims, like Dynamicland, to create a collaborative programming environment where each anyone in the space can write Javascript programs and interact with others. As in DL each program has a unique code and a colour encoding. It follows the same basic hardware model. That being a projector and camera on the ceiling and the paper "programs" (See Fig. 2.3.). This new vision of collaborative computing and somewhat "multi-modal" interaction is one of the initial inspirations and an important reference for this project.

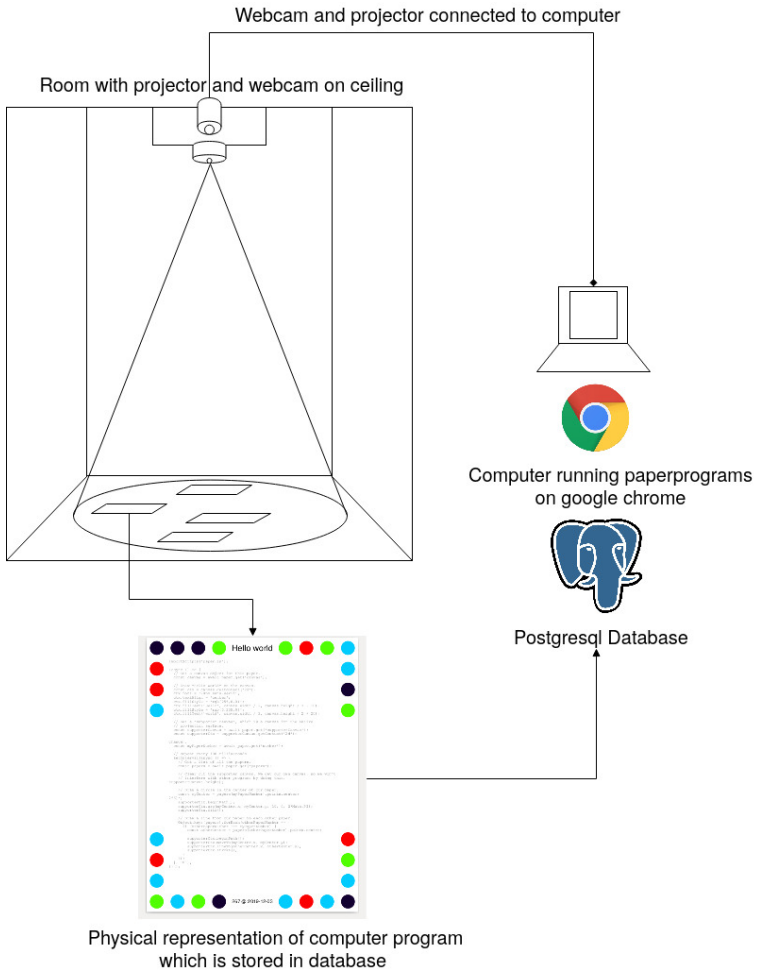

Figure 2.3: The initial physical schema: *Paperprograms*

2.5 Tangible bits - Ishii and Ullmer

Another significant reference exploring novel approaches to interaction involving physical objects was the paper: *Tangible bits: towards seamless interfaces between people, bits and atoms* (1997). It describes the motivation to for users to be able to "grasp and manipulate" bits, making them "tangible". The paper also presents three prototypes, – the *metaDESK*, *transBOARD* and *ambientROOM* and establish a new HCI approach "Tangible user interface[s]" (TUI) with equivalence to Graphical user interfaces (GUI's) [Ishii, 2002]. It is an academic precursor to Dynamicland and is a starting point for tangible interaction, merging *ubiquitous computing*, *augmented reality* and psychological approaches to HCI.

2.6 Implementation and abstraction

In the SAGE Handbook of Digital Technology Research's chapter on Haptic interfaces design parameters are listed:

- Cutaneous Perception
- Frequency
- Duration
- Rhythm
- Location
- Intensity
- Texture
- Kinesthetic Perception
- ...

These parameters present considerations for the design of such interfaces but also a formalisation of haptic interaction in the abstract [Higgins, 2015]. It takes the possible elements of 'hapticity' and lays them out. This motivated a second outcome to the implementation itself, to construct a *formal* specification for spatial and tangible interaction so as to describe the elements conceptually. This could then be used for further development of similar systems and allow for multi-disciplinary scientific experimentation. The benefits of having such a blueprint would be to present spatiality and tangibility (in relation to HCI) formally so as to allow for identification of elements for use.
Future researchability potential. [Lazar, 2017]

2.7 Multi-modal interaction

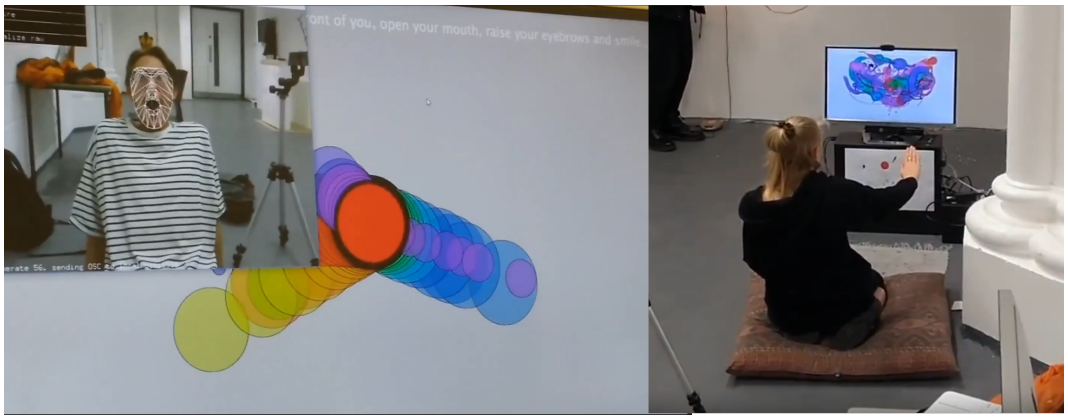

Figure 2.4: Multi-modal painting

An experimental project I produced in 2017 has also informed the direction of this project. This work was a multi-modal paint program where hand movements and facial expressions controlled different parameters of a paint program. This included colour, size and position of the stroke. Additionally the different modes of input were also controlling parameters on a looping synthesizer. The installation was multi-modal in input and output. It was an artwork in outlook but formed an initial experiment in designing interaction. The work was particularly successful with children, who quickly got the hang of the controls. It also included the combination of a variety of inputs to interaction with a variety of outputs.

Thought not necessarily the most effective or widely applicable it explored the capabilities of some more unusual interactive modes.

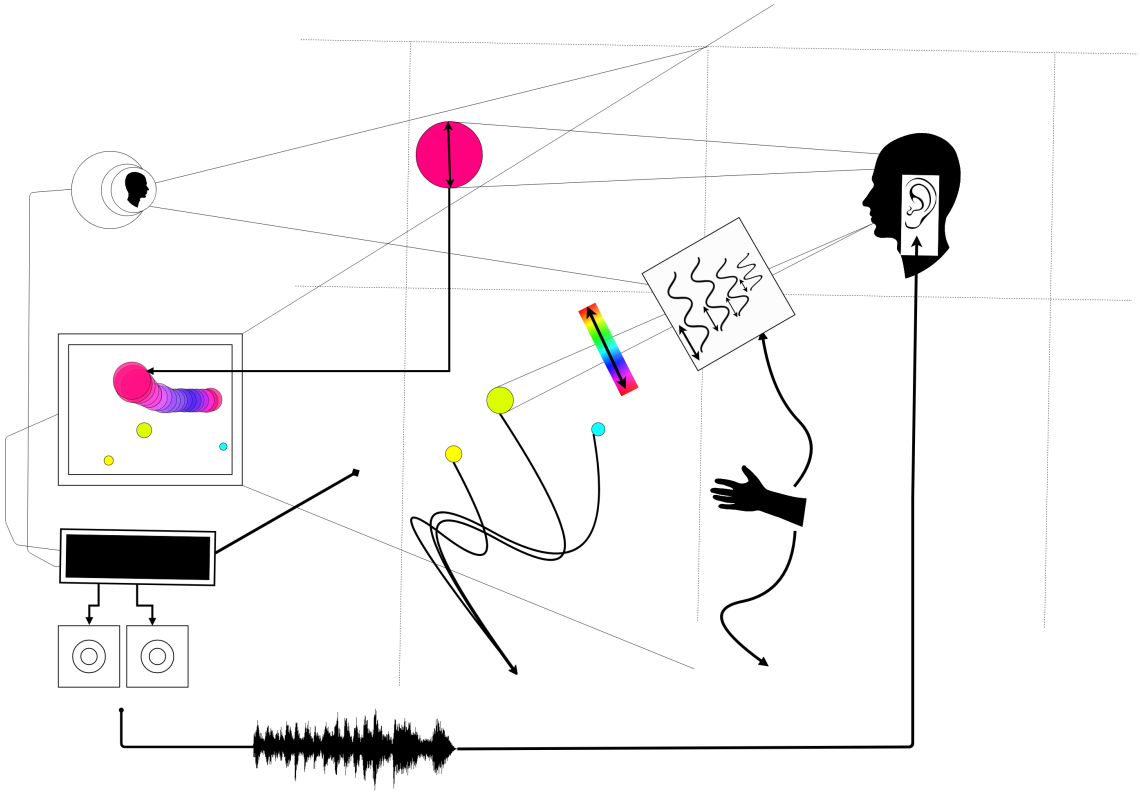

Figure 2.5: Modal schematic

Chapter 3

Specification and context

3.1 Brief

To sum up the fundamental principle of the style of interaction that this document aims to describe is summarised in the sentence below.

> Physical objects on an *action surface* have interactive properties, each object is both a sensor and actuator.

I provide this foundation so as to differentiate it between commonly used contemporary systems. It highlights that a 'live' surface will act as a space where objects are augmented with additional properties i.e. input and output to a computer system.

3.2 Technical

As in the original specification the aim was to create a system for spatial interaction. Initially I imagined it to work on a table top surface (in the end it was developed on a floor mat due to considerations in my development environment; see Chapter 4). The other principle component was that interaction would be based on the placement and movement of objects around the work-surface. The position and movements of these objects would be picked up by a camera and actuated by a projector; both situated above the surface looking down onto it. A horizontal setup would also be possible, with for example, magnetised components keeping the objects to a board. Alongside the spatial objects a computer keyboard may be used for additional input such as inputting text or formatting.

The original specification involved using *Paper Programs* and build on top of this. With the *PP* system, I planned to write a program/s to explore the psychology of interaction with such a system. This could take the form of a game-like psychology experiment. However, for risk of attempting a psychology thesis within a computing project focus has been put on creating and exploring the implementation and formalisation of the interaction model itself. Due to technical issues with *PP* and the motivation to explore an alternative interaction model, I decided to implement the system using **openFrameworks**, a C++ toolkit

for experimental application development. I chose this framework as it has straightforward 'out of the box' graphics capabilities as well as numerous add-ons. These include *OpenCV* [Bradski, 2000] wrappers and GUI libraries as well as an active community of users. This combination in one framework seemed suitable for quick experimentation and prototyping for this project. Other C++ libraries were to be considered; Cinder and just OpenCv. The physical setup would include a Projector and HD webcam and computer for running the application. See Fig. 4.2 for the software and hardware schematic for this technical conception.

3.3 Design considerations

Another design consideration I had in mind was accessibility. From my research into similar projects an aim was to create a similar system that could be open source and easily setup so that others could build on top of the system. This was another reason for using openFrameworks which is cross platform (Windows, OSx, IOS and Linux). This would mean with minor or no modification of the code, it could be run on any all the major desktop platforms. The hardware requirements are also the kind which are either cheaply (relatively) sourced or commonly available in educational institutions; one of the target areas that further development was envisioned.

Due to the limited scope of this project in both time and academic context a secondary theoretical component is conceived[1]. This is in the form of a theoretical specification and API for this project and similar systems. As discussed previously (2.6) a set of parameters and variables can form a useful part of a conceptual illustration and formalisation. This would include diagrammatic illustrations of different classes representing elements of the system, such as input and output and transformable objects.
The formalisation will address how specific various aspects of this interaction model can distribute and externalise cognitive work. *Annotating* (such as crossing out or underlining) and *Cogntive tracing* (manipulating items into different orders or structures) are two methods for externalising cognition. These two methods and others methods will be connected to elements of the interaction model. [Sharp, 2019]

[1] Due in part to the ongoing Coronavirus pandemic.

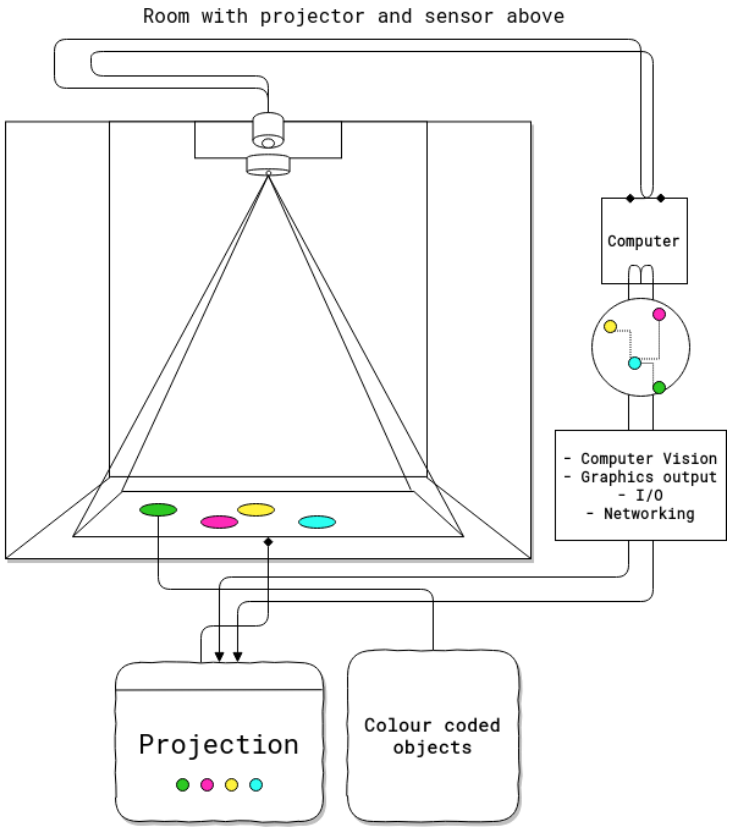

Figure 3.1: Abstract system schema

Chapter 4

Project in depth

4.1 Implementation details

The first essential component to get working was the computer vision. The core of this involves doing blob tracking for each colour in the `targetColours` array using the corresponding `contourFinder` object. Therefore we loop five times calling `findContours` passing in (by reference) the `camPix` an `ofPixels` object containing the camera pixel data for the active detection region.

```
// Check new frame
if(cam.isFrameNew()) {
    // Loop for number of colours and track target colours
    for(int i = 0; i < num_colours; i++){
        // if finding: find // cv on / off
        if(ss->find) ss->contourFinders[i].findContours(camPix);
    }
}
```

Five different colours were chosen as it is the same as in *PP*. Given its identical hardware setup it seemed a good number. Having more colours means thresholds will be lower so as to distinguish between less distinct colours; for example pink and red. The contour finder has a number of parameters which allow for fine grained control over the tracking. They are listed below:

- `TargetColor`
- `Threshold`
- `MinArea`
- `MaxArea`
- `MinAreaRadius`
- `MaxAreaRadius`

Architecturally the application is comprised of two windows the **GUI** and **Projector**, represented in two classes `ofApp` and `Projector`. The **GUI** window is a control panel or the computer vision tracking. Controls for the parameters are available in the **GUI** window as

well handles to crop the active region part of the camera frame were the computer vision happens. In the screenshot (Fig. 4.1) the tracking parameters are seen on the left and the target colours are on the right. In the center the rectangle with the pink circles on upper left and bottom right corners is the active detection region.

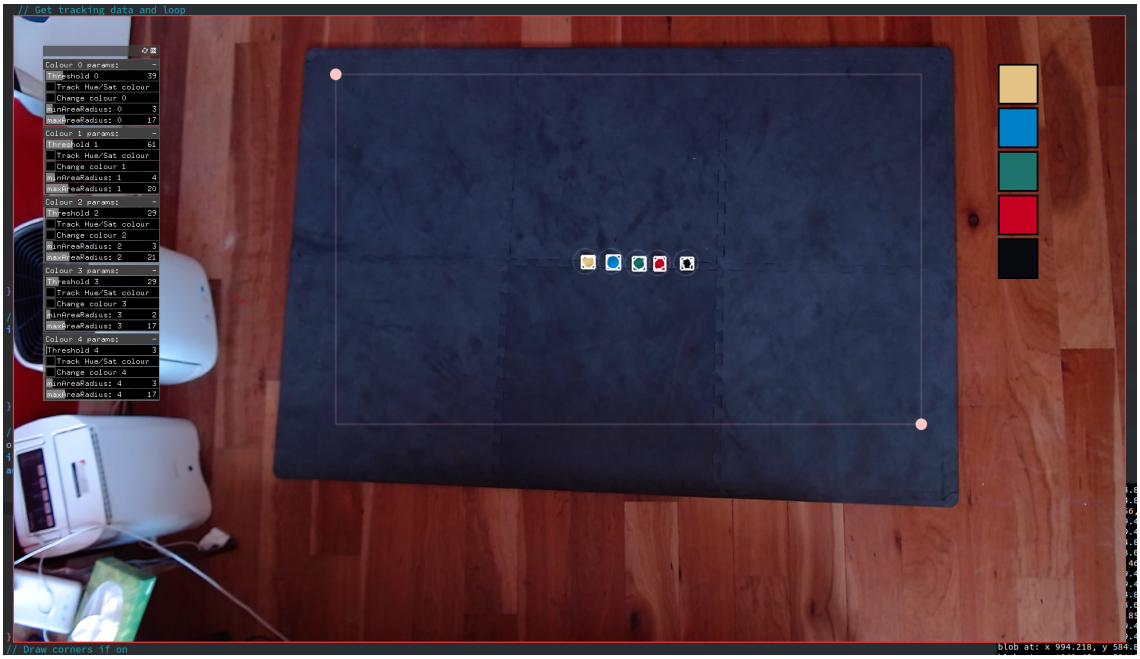

Figure 4.1: GUI window.

The other main window used is in the **Projector** class. This deals with the display of on the reaction surface.

1. Finalised design
2. Development

4.2 Final outcome

4.3 Abstract Spec

4.4 API

Currently in the API is in its most rudimentary state. Colour blobs, location , id

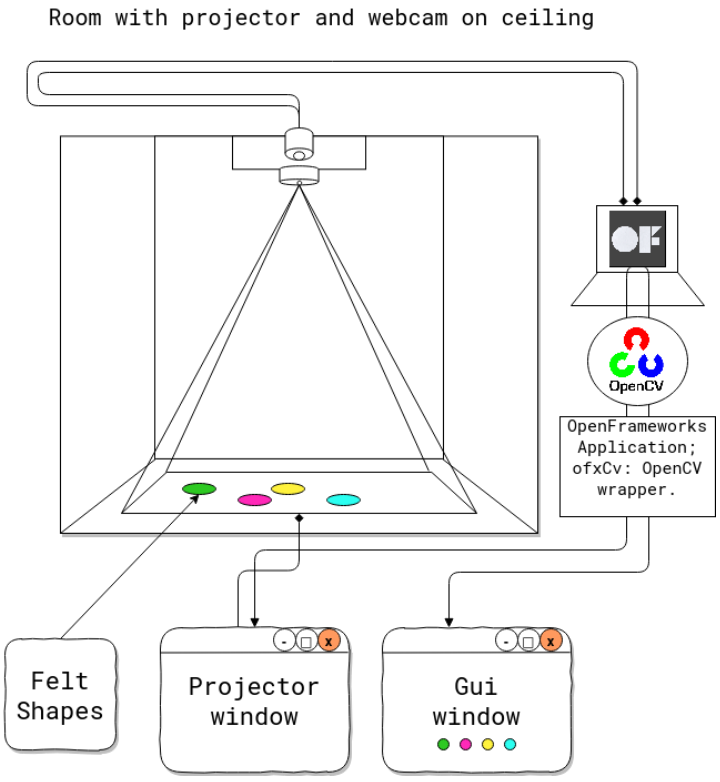

Figure 4.2: Finalised system schema

Chapter 5

Creative process and software testing.

As mentioned *Paperprogams* was a starting point for playing around with but I found that I couldn't set it up and have it stable enough to develop on. It also suffers from being quite slow, due to the Computer Vision and graphics being done in the browser (it uses a version of OpenCv compiled to WebAssembly) [JP, sorg]. While WebAssembly has the scope for doing high-performance computation in the browser but I found there was still a significant lag from detecting papers to projecting back down on to them. Another branch which had implemented blob detection on the GPU I also found to be slow and unstable (Link to pull request), this may have been due to my lighting and camera setup.
After testing with *PP* and finding it to be unstable and difficult to develop on Cinder and OpenCV were considered. Another reason for moving away from *PP* was it already being a fully fledged system in itself. It has potential for developing some interesting tools collaboratively but for this solo project working alone the social aspect would not be utilised.

5.1 pimapper, projection mapping issue.

5.2 Goverened by

1. ...technical implementability
2. ...research and experience

5.3 Raspberry pi testing

Chapter 6

Debugging and problem solving

Chapter 7

Evaluation and Conclusions

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