MINISTRY OF NATIONAL EDUCATION

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

FACULTY OF AUTOMATION AND COMPUTER SCIENCE
COMPUTER SCIENCE DEPARTMENT

# REACTIVE PROGRAMMING BASED GESTURE DETECTION IN VIRTUAL REALITY USING LEAPMOTION

LICENSE THESIS

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Supervisor: Assist. Prof. Dr. Eng. Adrian SABOU

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**REACTIVE PROGRAMMING BASED GESTURE DETECTION IN VIRTUAL REALITY USING LEAPMOTION**

1. **Project proposal:** *A Reactive Programming oriented Unity asset for gesture detection using the LeapMotion controller*
2. **Project contents:** *(enumerate the main component parts) Presentation page, advisor's evaluation, title of chapter 1, title of chapter 2, ..., title of chapter n, bibliography, appendices.*
3. **Place of documentation:** *Technical University of Cluj-Napoca, Computer Science Department*
4. **Consultants:** Assist. Prof. Dr. Eng. Adrian SABOU
5. **Date of issue of the proposal:** November 1, 2018
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Supervisor: ______________________________

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Nume, Prenume

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Semnătura

# Contents

# Chapter 1

# Introduction - Project Context

Virtual Reality is an experience that has gained huge popularity in the recent years. Because of this new means of interaction with this virtual world are needed and they should feel as natural as possible. Ergo, hand tracking and gesture detection is a "must have" for modern VR applications.

## 1.1 Virtual reality

The term "virtual" began its life in the late 1400s, meaning "being something in essence or effect, though not actually or in fact" [1], but, in the IT context, the word has the meaning "not physically existing but made to appear by software" [1]. The original use of the phrase "virtual reality" is found in French playwright' Antonin Artaud collection of essays *Le Théâtre et son double*, first published in 1938 [2].

### 1.1.1 History

The precise roots of virtual reality are challenged, partially because of how hard it was to formulate a definition of an alternate reality notion. In 1968, Ivan Sutherland created what was widely regarded as the first head-mounted display system for use in immersive simulation applications, with the help of his students. In the next two decades, VR devices were mainly used for medical, automobile industry design, militry training and flight simulation purposes.

The 1990s saw the first commercially extensive release of consumer headsets, notably *Sega VR* (1991) and *Sega VR-1* (1994) launched by Sega, and *Nintendo's Virtual Boy* (1995). The 2000s were a period of comparative indifference from the public and investment towards VR techniques available on the market. Google launched *Street View* in 2007, a service that offers panoramic views of a growing amount of global locations such as highways, indoor houses and rural regions, which also integrates a stereoscopic 3D mode as of 2010.

The modern, consumer version of headsets started developing in the early 2010s. In 2013, Valve Corporation found and freely shared the breakthrough of low-persistence screens that make it possible today to show VR content lag-free and smear-free.

This discovery was quickly adopted by the other companies on the market, with Sony announcing *Project Morpheus* in 2014 and Google announcing *Cardboard* in 2015. In 2016, HTC released and shipped the first units of *Vive SteamVR*, the first major commercial headset for average users.


Figure 1.1: Project Morpheus (PlayStation VR) at gamescom in 2015

### 1.1.2 Modern technology

Present virtual reality headset displays rely on smartphone technologies including: gyroscopes and motion sensors for head, hand and body position monitoring, tiny high definition stereoscopic displays and small, lightweight and powerful computer processors.

Special input devices are required for interaction with the virtual world, such as hand controllers, haptic gloves, 3D mouse and optical tracking sensors. Both haptic gloves and hand controllers provide force feedback (in the form of vibration), with haptic gloves providing also feedback in the form of response force (like when picking a rubber duck).

## 1.2 Gesture recognition

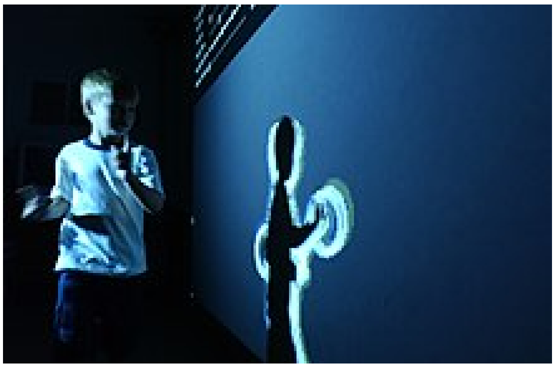


Figure 1.2: A child being recognized by a simple gesture detection algorithm

Gesture recognition is an active research field with the objective of comprehending human gestures through mathematical models. Gestures can come from any posture or position of the body, but they typically come from the hand. Without actually touching them, users can use simple motions to command or communicate with machines.

Gesture recognition may be seen as a means for machines to commence to comprehend human body language, establishing a stronger link between computers and individuals than conventional text user interfaces or even GUIs (graphical user interfaces), which still restrict most inputs to the keyboard and/or mouse and communicate naturally with no mechanical instruments.

## 1.3 Reactive programming

Reactive programming is a declarative programming paradigm concerned with asynchronous data streams and the propagation of change. With this paradigm it is feasible to easily express static (e.g. lists) or dynamic (e.g. events) information streams and to also indicate that an implied dependency remains within the related implementation model, which promotes the automatic propagation of the altered information stream.

Examples of Reactive Programming include hardware description languages (HDLs), such as VHDL or Verilog, in which changes are modeled as they propagate through a circuit. As a manner to optimize the development of dynamic user interfaces and virtually-real-time system animation, reactive programming has been suggested.

# Chapter 2

# Project Objectives and Specifications

## 2.1 Introduction

The purpose of this chapter is to collect, analyze and define high-level needs and features of the Unity asset named Fluent Motion. It focuses on the capabilities needed by the stakeholders and the target users, and why these needs exist.

## 2.2 Positioning

### 2.2.1 Problem statement

As Virtual Reality (VR) is becoming more accessible to the average person, more problems arise with the means of interacting with the VR world. A solution to this issue is the Leap Motion hand tracking device, which offers a natural means of human-VR interaction. The problem with Leap Motion is its non-friendly Application Programmer Interface (API).

| **The problem of** | Leap Motion's unfriendly API |
|---|---|
| **affects** | developers in the VR field who use Leap Motion |
| **the impact of which is** | a limited number of applications using Leap Motion |
| **a successful solution would be** | easy to use<br>fluent (in terms of code readability)<br>adhere to the reactive programming paradigm<br>available on Unity's asset store |

### 2.2.2 Product Position Statement

Fluent Motion comes as a union between three technologies – Virtual Reality, Leap Motion and ReactiveX.

So far, Virtual Reality and Leap Motion already are integrated (by means of LeapMotion's API), but ReactiveX can offer a more fluent way of expressing what an application using the first two mentioned technologies together.

| | |
|---|---|
| **For** | Virtual Reality developers |
| **who** | use Leap Motion |
| **Fluent Motion** | is an extension of Leap Motion using ReactiveX |
| **that** | offers a fluent API for Leap Motion |
| **unlike** | the default API |
| **Fluent Motion will** | be easy to use<br>be fluent (in terms of code readability)<br>adhere to the reactive programming paradigm |

## 2.3 Stakeholder and User Descriptions

### 2.3.1 Stakeholder summary

| Name | Description | Responsibilities |
|---|---|---|
| **Developer (VR)** | Person who wants to create Virtual Reality applications | Use Fluent Motion |
| **Developer (Fluent Motion)** | Person who creates and maintains Fluent Motion | Create, improve and offer technical support for Fluent Motion |

### 2.3.2 User summary

| Name | Description | Responsibilities | Stakeholder |
|---|---|---|---|
| **Developer (VR)** | Person who wants to create VR applications | Use Fluent Motion | *Developer (VR)* |

### 2.3.3 User environment

#### 2.3.3.1 Users

The API will be used by developer teams of any size.

#### 2.3.3.2 Infrastructure

The infrastructure needed by Fluent Leap is an aggregation of the hardware requirements of the combined systems and technologies, i.e.:

| | |
|---|---|
| Operating system | **Windows 7 SP1**, **Windows 8.1** or later, **Windows 10** |
| Middleware | **SteamVR** platform |
| Additional hardware | **Leap Motion** hand tracking device<br>a VR headset (at the time of writing, **Occulust Rift**, **HTC Vive** or **Valve Index**) |
| Miscellaneous | **.NET Framework 4.6** or newer<br>**Unity** 5.6 or later |

### 2.3.4 Summary of key stakeholder or user needs

| Need | Priority | Concerns | Current solution | Proposed solution |
|---|---|---|---|---|
| **VR API** | 0 | Developer | Leap Motion default API, using **ANSI C** language imperative style | Fluent Motion, using **C#** language and ReactiveX |
| **Desktop API** | 1 | Developer | Leap Motion default API, using **ANSI C** language impertive style | Fluent Motion, using **C#** language and ReactiveX |
| **Usability** | 0 | Developer | Leap Motion defualt API, using **ANSI C** language imperative style | Fluent Motion, using **C#** language and ReactiveX |

### 2.3.5 Alternatives and competetion

External competition is represented by the current API offered by LeapMotion.

## 2.4 Product overview

The API should provide all the functionality already provided by Leap Motion's default API, but in a higher-level language.

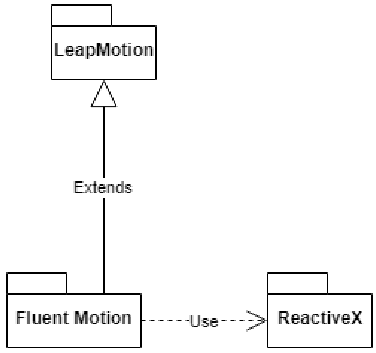


Figure 2.1: Fluent Motion architectural diagram

### 2.4.1 Product perspective

This product will extend existing features from Leap Motion, making them more readable and developer friendly.

### 2.4.2 Assumption and dependencies

For developers:

| | |
|---|---|
| Operating system | **Windows 7 SP1**, **Windows 8.1** or later, **Windows 10** |
| Middleware | **SteamVR** platform |
| Additional hardware | **Leap Motion** hand tracking device<br>a VR headset (at the time of writing, **Occulust Rift**, **HTC Vive** or **Valve Index**) |
| Miscellaneous | **.NET Framework 4.6** or newer<br>**Unity** 5.6 or later |

For end products that reference Fluent Motion:

| | Minimum | Recommended |
|---|---|---|
| **CPU** | Intel Core i3-8100 | Intel i5-4590 or AMD FX 8350 equivalent |
| **GPU** | Nvidia GeForce GTX 1060 3GB or AMD Radeon RX 570 | Nvidia GeForce GTX 970 or AMD Radeon R9 290 equivalent |
| **Memory** | 8GB | 16GB |
| **Output** | HDMI 1.4, DisplayPort 1.2 | DisplayPort 1.2 |
| **Input** | 2x USB 3.1 gen 1 (Type-A) | 2x USB 3.1 gen 2 (Type-A) |

## 2.5 Product features

1. **Hands module**

   The module that will allow the developer to use the two hands objects from the scene in order to detect gestures or motions, and assign callbacks when certain criteria regarding the hands are met.
   This module is available in both Virtual Reality and Desktop modes.

2. **Fingers module**

   The module that will allow the developer to use the fingers (individually or in groups) in the scene for detecting gestures or motions, and assign callbacks when certain criteria regarding the fingers are met.
   This module is available in both Virtual Reality and Desktop modes.

3. **Virtual Reality module**

   The module that will allow the user to develop Virtual Reality applications. This module will act as a dependency to other modules.
   It isn't mutually exclusive with the Desktop Module, BUT at least one of the two must be present.

4. **Desktop module**

   The module that will allow the user to develop applications using Leap Motion in desktop mode.
   This module will act as dependency to other modules. It isn't mutually exclusive with the Virtual Reality Module, BUT at least one of the two must be present.

5. **Gesture definition module**

   The module that allows the user to define new gestures besides already existing ones. This module depends on either Virtual Reality module or Desktop module, and on either Hands module, Fingers module or both.

6. **Gestures module**

   This module will provide defitions to some basic gestures (like finger pointing to some object, hand swipe, etc.). This module depends on either Virtual Reality module or Desktop module, and on either Hands module and Fingers module.

7. **Demo**

   This module will provide some demonstrative code for new users to acquaint themselves with the basic flows and code syntax of Fluent Motion.

## 2.6 Other product requirements

1. **High readability**

   The main purpose of the API is to be fluently read, i.e. the code should sound almost like natural language when read by other developers.

2. **Open source**

   The project will be open source and anyone will be able to contribute to it.

3. **Performance**

   Virtual Reality applications shouldn't fall bellow 80 frames per second (FPS), and, as such, the API shouldn't introduce a high processing time per frame to to fall below that threshold.

4. **Scalability**

   The API should support detecting up to 10 distinct gestures per application and interacting with at least 20 objects (excluding hand to hand interactions).

5. **Maintainability**

   The VR world is still young and technologies evolve fast, so the API should be highly maintainable to keep its edge.

6. **Extendibility**

   The API should be easily extendable by any backer on Git.

# Chapter 3

# Bibliographic research

## 3.1 Gestures

A gesture is a type of non-verbal communication in which real physical movements transmit specific messages, both in place or in combination with speech. Gestures include movement of the hands, face, or other parts of the body. Gestures differ from physical non-verbal communication that does not communicate specific messages, such as purely expressive displays, proxemics, or displays of joint attention. [3]

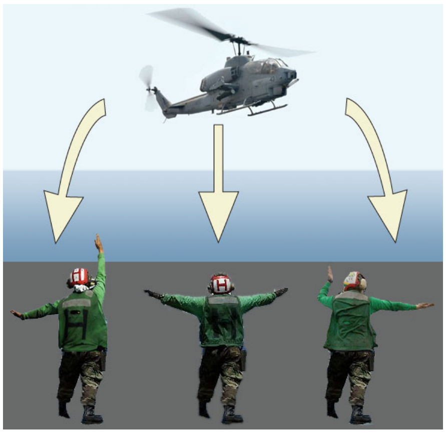


Figure 3.1: Military air marshallers use hand and body gestures to direct flight operations aboard aircraft carriers

Gestures can be of two types: *informative (passive)* or *communicative (active)*. *Informative gestures* are passive gestures that provide details about the speaker as a person and not about what the speaker is attempting to communicate, while *communicative gestures* are deliberately and meaningfully made by a individual as a means of heightening or altering speech generated in the larynx (or with hands in the situation of sign languages) although he or she may not be actively conscious of the fact that they produce communicative gestures.

Within the realm of communicative gestures, the first distinction to be made is between gestures made with the hands and arms, and gestures made with other parts of the body, such as head or shoulders. From now on, we shall focus only on manual gestures.

### 3.1.1 Manual gestures

Manual gestures are split into four categories:

1. **Symbolic (emblematic)**
   These are standard, culture-specific gestures which can be used as a substitute for words (like waving your hand to say "hello" or "googbye"). In distinct cultural contexts, a single emblematic gesture can have a very distinct meaning, varying from complimentary to extremely offensive. Symbolic gestures are iconic gestures that are widely recognized, fixed, and have conventionalized meanings. [4]

2. **Deictic (indexical)**
   Deictic gestures may happen concurrently or in place of vocal expression. Deictic gestures are gestures consisting of indicative motions or pointing movements. They often replace words and pronouns like "this", "there" or "that".

3. **Motor (beat)**
   In verbal speech, motor or beat gestures typically consist of brief, rhythmic, repetitive motions strongly linked to sentence construction. Beat gestures do not happen separately of verbal expression, unlike symbolic and deictic gestures. Some individuals wave their hands, for instance, as they talk to highlight a word or sentence. These gestures are closely coordinated with speech.

4. **Lexical (iconic)**
   Other spontaneous gestures used in speech known as iconic gestures are more content-filled, and the significance of the co-occurring voice may echo, or be elaborated. They portray elements of pictures, behavior, individuals, or items in space. For instance, a gesture depicting the throwing act may be synchronous with the saying, "He threw the ball right into the window.".

## 3.2 Gesture recognition

Gesture recognition is an active research field with the objective of comprehending human gestures through mathematical models. Gestures can come from any posture or position of the body, but they typically come from the hands. Without actually touching them, users can use simple motions to command or communicate with machines.

Gesture recognition may be seen as a means for machines to commence to comprehend human body language, establishing a stronger link between computers and individuals than conventional text user interfaces or even GUIs (graphical user interfaces), which still restrict most inputs to the keyboard and/or mouse and communicate naturally with no mechanical instruments.

There are two gesture types in the human-computer interaction context:

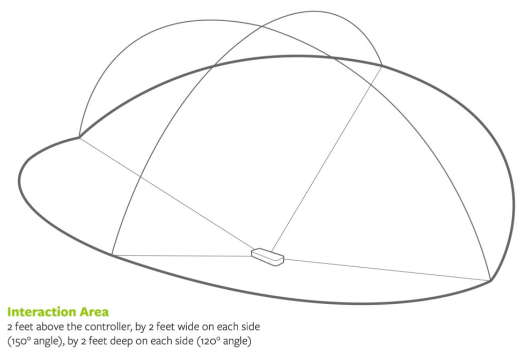
1. **Offline gestures**
   These gestures are processed after the object is interacted with by the user (e.g. activate a menu gesture).

2. **Online gesture**
   Direct manipulation gestures, like scaling or moving an object.

## 3.3 Leap Motion

The *Leap Motion Controller* is a tiny peripheral USB device intended to be facing upwards on a physical desktop, but can also be mounted on a VR headset.


(a) The LeapMotion controller




(b) The interaction area

Figure 3.2: The LeapMotion system

### 3.3.1 Hardware

The *Leap Motion Controller* is really quite straightforward from a hardware view. Two cameras and three infrared LEDs are the core of the device. These track infrared light with a wavelength of 850 nanometers, which is outside the visible light spectrum. [5]

The unit has a big interaction room of 0.22 m$^3$ thanks to its wide-angle glasses, which takes the form of an inverted pyramid – the intersection of the areas of perspective of the binocular cameras (see figure 3.2b). The viewing range of the device is 60cm to 80cm, depending on the version of the firmware used.

This raw data is then stored in the device's local memory and then sent via USB to the *Leap Motion tracking software*. As the cameras work with near-infrared light, the data is in the form of grayscale stereo images, as shown in figure 3.3.

### 3.3.2 Sofware

It's time for some heavy mathematical lifting once the picture information is streamed to the computer. The *Leap Motion Controller* does not produce depth maps despite common misconceptions - instead it applies sophisticated algorithms to the raw sensor information.

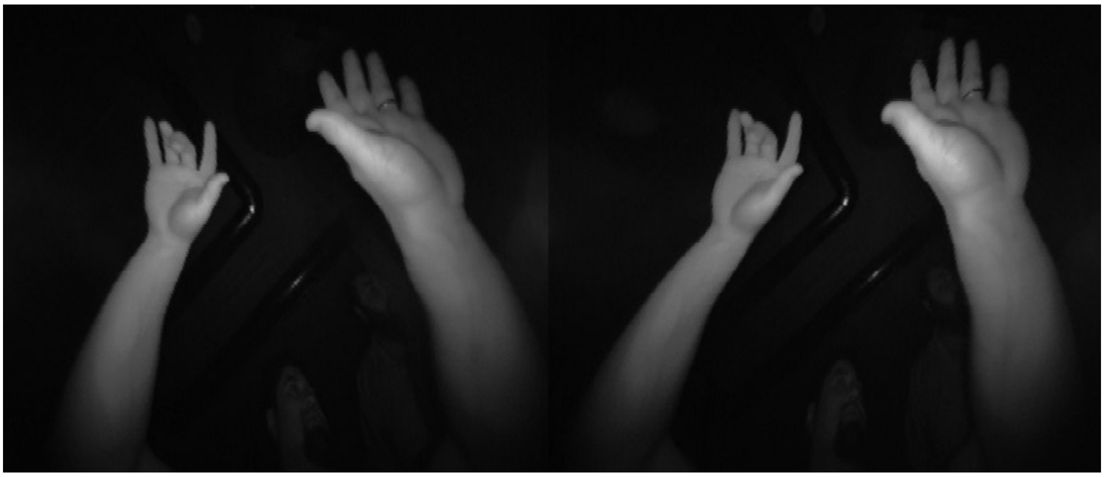


Figure 3.3: Leap Motion raw data

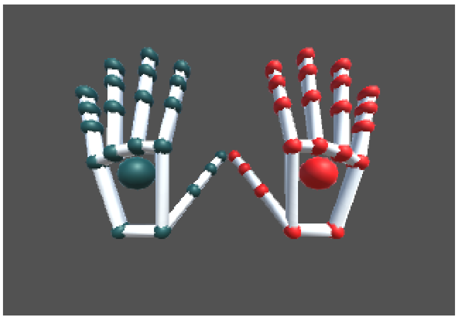


Figure 3.4: Capsule hands

The Leap Motion Service first compensates background objects (e.g. head) and lightning, and then extracts from the data the relevant information - arms, hands and fingers.

Though a transport layer, the results(frames) are fed to the *Leap Motion Control Panel* or to native and web clients. These orgaize the data into an object-orietented structure.

## 3.4 Reactive Extensions

ReactiveX is a library for composing asynchronous and event-based programs by using observable sequences. [6]

It extends the observer pattern to support data and/or event sequences and provides operators that help you compose sequences declaratively while abstracting issues such as low-level threading, synchronization, thread security, concurrent data structures, and non-blocking I/O.

Table 3.1 shows how observables integrate in the programming world.

| | single items | multiple items |
|---|---|---|
| synchronous | T GetData | IEnumerable<T> GetData |
| asynchronous | Awaitable<T> GetData | Observable<T> GetData |

Table 3.1: Observable position in multiple items and asynchronous world

### 3.4.1 Why use observables?

ReactiveX observables are intended to be ***composable, flexible***and ***less opitionated***. These provide a huge advantage over structures like Java *Futures* or C# *Awaitables*, because it removes the need for ambiguous nesting of callbacks.

RX Observables also offer three methods for of flow control - *OnNext*, *OnError* and *OnCompleted* - which give the programmer very much liberty.

`Iterable`

```
getDataFromLocalMemory()
  .skip(10)
  .take(5)
  .map({ s -> return s + " transformed" })
  .forEach({ println "next => " + it })
```

`Observable`

```
getDataFromNetwork()
  .skip(10)
  .take(5)
  .map({ s -> return s + " transformed" })
  .subscribe({ println "onNext => " + it })
```

Figure 3.5: Iterable vs Observable

# Chapter 4

# Analysis and Theoretical Foundation

Together with the next chapter takes about 60% of the whole paper

The purpose of this chapter is to explain the operating principles of the implemented application. Here you write about your solution from a theory standpoint - i.e. you explain it and you demonstrate its theoretical properties/value, e.g.:

- used or proposed algorithms
- used protocols
- abstract models
- logic explanations/arguments concerning the chosen solution
- logic and functional structure of the application, etc.

YOU DO NOT write about implementation.

YOU DO NOT copy/paste info on technologies from various sources and others alike, which do not pertain to your project.

# Chapter 5

# Detailed Design and Implementation

Together with the previous chapter takes about 60% of the paper.

The purpose of this chapter is to document the developed application such a way that it can be maintained and developed later. A reader should be able (from what you have written here) to identify the main functions of the application.

The chapter should contain (but not limited to):

- a general application sketch/scheme,
- a description of every component implemented, at module level,
- class diagrams, important classes and methods from key classes.

# Chapter 6

# Testing and Validation

About 5% of the paper

## 6.1 Title

## 6.2 Other title

# Chapter 7

# User's manual

In the installation description section your should detail the hardware and software resources needed for installing and running the application, and a step by step description of how your application can be deployed/installed. An administrator should be able to perform the installation/deployment based on your instructions.

In the user manual section you describe how to use the application from the point of view of a user with no inside technical information; this should be done with screen shots and a stepwize explanation of the interaction. Based on user's manual, a person should be able to use your product.

## 7.1 Title

## 7.2 Other title

# Chapter 8

# Conclusions

About. 5% of the whole
Here your write:

- a summary of your contributions/achievements,
- a critical analysis of the achieved results,
- a description of the possibilities of improving/further development.

## 8.1 Title

## 8.2 Other title

# Bibliography


[1] 2019. [Online]. Available: https://www.etymonline.com/search?q=virtual

[2] A. Artaud, *The Threatre and its Double*, 1938.

[3] K. Adam, *Gesture: Visible Action as Utterance.* Cambridge University Press, 2004.

[4] R. M. K. et al., *Lexical Gestures and Lexical Access: A Process Model.* Cambridge University Press, 2001, pp. 261–283.

[5] A. Colgan, "How does the leap motion controller work?" 2014. [Online]. Available: http://blog.leapmotion.com/hardware-to-software-how-does-the-leap-motion-controller-work/

[6] 2019. [Online]. Available: http://reactivex.io/intro.html

# Appendix A

# Relevant code

```
 /** Maps are easy to use in Scala. */
object Maps {
  val colors = Map("red" -> 0xFF0000,
                   "turquoise" -> 0x00FFFF,
                   "black" -> 0x000000,
                   "orange" -> 0xFF8040,
                   "brown" -> 0x804000)
  def main(args: Array[String]) {
    for (name <- args) println(
      colors.get(name) match {
        case Some(code) =>
          name + " has code: " + code
        case None =>
          "Unknown color: " + name
      }
    )
  }
}
```

# Appendix B

# Other relevant information (demonstrations, etc.)

# Appendix C

# Published papers