

Decision Support and Business Intelligence

Information Technologies for Business Intelligence

Master Thesis

Oky PURWANTININGSIH

Visual Analytics on Human Body Movement Data Applied on Healthcare

prepared at Laboratoire d'Informatique, de Robotique et de
Microélectronique de Montpellier

Defended on September ?, 2015

Advisor : Arnaud SALLABERRY - LIRMM arnaud.sallaberry@lirmm.fr
Jerôme AZÉ - LIRMM jerome.aze@lirmm.fr
Supervisor : Nacéra BENNACER - Centrale Supélec nacera.bennacer@supelec.fr

Abstract: The main objective of this Master thesis is to ...
To achieve this goal, we use ...

All this research work has been implemented in ...
Keywords: Keyword1, 2, ...

Acknowledgments

Last thing to do :-)

Contents

1	Introduction	1
1.1	Motivation	1
1.2	Methodology	2
1.3	Thesis Outline	3
2	Domain Problem Characterization	5
2.1	Hammer and Planks Game Dynamics	5
2.2	Target User Questions	5
2.3	Visualization Requirements	6
3	Related Works	9
3.1	Visualization of Serious Game Result	9
3.2	Visualization of Time Series Data	11
3.3	Visualization of Movement Data	13
3.4	Data Visualization Tool	17
4	Data Abstraction	19
4.1	Game Events Structure	19
4.1.1	Event Category	19
4.1.2	Game World Coordinates	19
4.1.3	Screen Speed	20
4.2	Clustering Algorithm	20
5	Visual Mappings And Interactive Functionality	23
5.1	Early version of the Visualization	23
5.2	Session Visualization	24
5.2.1	Stacked Graph	24
5.2.2	Heat Map	25
5.3	Summary Visualization	27
5.3.1	Visualization by range of x-area	27
5.3.2	Visualization by number of events	29
5.3.3	Interaction Technique	29
5.4	General Interface	30
6	Case Studies	31
6.1	Case Study 1: Normal Player	31
6.2	Case Study 2: Patient	32
7	Conclusion	35
A	Appendix Case Studies	37
	Bibliography	45

List of Figures

1.1 Hammer and Planks Screenshot	2
1.2 Munzner's Visualization Design Model with four nested layers	2
2.1 Hammer and Planks movement type	6
3.1 Visualization used in [19] depicting the degree of forearm movement overtime	10
3.2 Visualization used in [20] depicting the speed of movement (m/s) of forearm overtime	10
3.3 Flow Map	12
3.4 Spatio-Temporal Event Visualization	12
3.5 Theme River	13
3.6 Car Trajectories clustered by route similarity	14
3.7 Presence of cars in Milan in different time period	15
3.8 Motion Trail	16
3.9 Color Belt depicting gymnast body movement	16
3.10 MotionExplorer interface	17
3.11 Some of visualizations developed with D3.js	18
3.12 3D visualization of world population developed in Three.js	18
5.1 First visualization version for (T1.3) and (T1.4) using Scatter Plot	23
5.2 First visualization version for (T1.1) and (T1.2) using Line Chart	24
5.3 Stacked Graph with Linear Layout	25
5.4 Different Layout of the Stacked Graph representing number of events over x-axis	26
5.5 Heatmap	26
5.6 Summary Chart divided by range of x-area	28
5.7 Summary Chart divided by range of x-area, clustered with threshold = 4	28
5.8 A section in Summary Visualization	28
5.9 Summary Chart divided by number of events	29
5.10 Interaction Bar for Summary Visualization	30
5.11 Application Interface	30
A.1 Stacked Graph comparison of Session 1 and Session 20	37
A.2 Heatmap comparison of Session 1(left) and Session 20(right)	38
A.3 Stacked Graph comparison of Session 1 and Session 20 for Enemy	38
A.4 Heatmap comparison of Session 1(left) and Session 20(right) for Enemy	38
A.5 Summary Visualization by x-range	39
A.6 Summary Visualization by x-range, filtered for positive events	39
A.7 Summary Visualization by x-range, filtered for positive events and clustered	39
A.8 Summary Visualization by number of events, filtered for positive and negative events	40
A.9 Stacked Graph of Session 10	40

A.10 Heatmap of Session 10	41
A.11 Stacked Graph of Session 10, filtered by bonus	41
A.12 Heatmap of Session 10, filtered by bonus	42
A.13 Summary visualization of Patient 6	42
A.14 Summary visualization of Patient 6, filtered by neutral events	43
A.15 Summary visualization of Patient 6, clustered	43
A.16 Summary visualization of Patient 6 with sections divided by number of events, filtered by positive and negative events	43

List of Tables

4.1 Event Type grouping	20
-----------------------------------	----

CHAPTER 1

Introduction

The advancement of gaming device technology such as Kinect, Wii Balance Board, Wii Remote, PlayStation Move, etc. has enabled players to control and interact with the game console through body movement. In healthcare, such technology are used in serious game which can help the users (doctors, patients, researchers, etc.) perform health related activity such as patients' rehabilitation and training[19, 6, 12]. One example of such game is Hammer and Planks which was designed to train the equilibrium of patient with balance disorders (specifically for hemiplegic people)[9]. A person with hemiplegic is paralyzed on one side of the body¹. Therefore, the gameplay is designed so that the player has to move their body to right, left, front and back in order to train their affected side of the body. To support the purpose of rehabilitation, the healthcare professionals need to analyse the movement to make a correct diagnostic of patients' progress and to adjust the difficulty level for the next rehabilitation session. In this thesis, I discuss the design of an interface to help healthcare professional to understand the data generated from the game.

1.1 Motivation

Hammer and Planks tells the story of a pirate named John K. One day a meteor fell down on John's ship and ruin it. There is a little left from his boat but it is still enough to build a new basic boat with what's left. While navigating his ship to collect driftwood/plank to upgrade it (hence the name Hammer and Planks), he also wants to find the ship which showered meteor and destroyed his ship. The game itself is a vertical shooter game. The game world is in a 2D environment vertically scrolling from top to bottom in which the player navigate a ship from left to right and top to bottom. The player has to defeat all enemies which come on his way and he has to avoid being destroyed by bullets, reefs and other obstacles. Throughout the game the player has to collect bonuses to improve the ship. The game is usually played in short and intense phase and thus requires a lot of concentration[9].

Currently, the game provides some charts which visualize player's body movement with respect to the horizontal axis and vertical axis. However, the information that can be gathered from the visualization is not enough for the healthcare professional to be able to establish an informed diagnostic. It's hard to know how often the player move to right or left. It's also not possible to know to which type of events (ie. avoiding an enemy, catching the bonuses) the movement is related to. Which is crucial since the therapist need to know if the player is able to develop strategy to play the game overtime. The existing visualization also provides chart to show the evolution of player's performance and

¹http://www.hemihelp.org.uk/hemiplegia/what_is_hemiplegia



Figure 1.1: Hammer and Planks Screenshot

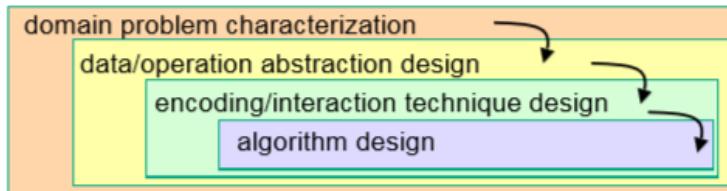


Figure 1.2: Munzner's Visualization Design Model with four nested layers

total movement for all game sessions. However, the evolution of player's body movement (horizontally or vertically) is not depicted.

The purpose of this thesis is to address the problem mentioned by proposing four types of visualization: (i) a visualization which provides information related to a certain type of event and body movement for each one game session (ii) a visualization which represents a certain type of event, body movement, and the speed in which the event is occurring in one game session (iii) a visualization where healthcare professionals can analyse the evolution of player's body movement in throughout all sessions. For the third visualization, there are two options in which the user can analyse the movement: by area of movement or by the number of movement in an area.

1.2 Methodology

To ensure that the visualization to be designed would satisfy the information needed by healthcare professionals, I followed the Nested Process Model proposed by Tamara Munzner [16]. The model is divided into 4 levels: Domain Problem Characterization, Data/Operation Abstraction Design, Encoding/Interaction Technique Design, and Algorithm Design. These levels are nested; the output of a higher level will be the input for the lower level as shown in the figure above.

In domain problem characterization level, I discuss what kind of information needed

by health professional from the visualization. The output of this level would be a list of tasks that need to be solved by the visualization application. I then identifies the data structure which can support these tasks in the Data/Operation Abstraction Design level. In the third level, a good visualization and interaction technique which can support the tasks will be defined. For this thesis, I leave out the algorithm design level since there is no new algorithm proposed.

1.3 Thesis Outline

The remainder of this thesis is organized as follows. Chapter 2 discuss the domain problem characterization. Chapter 3 explores related work. The data abstraction is presented in Chapter 4. The Visual Mapping and Interactive Functionality of the proposed visualization are discussed in details in Chapter 5. Chapter 6 provides some case studies used to evaluate the approach and finally, chapter 7 concludes the thesis.

CHAPTER 2

Domain Problem Characterization

In order to clearly understand the problems faced by the healthcare professional in interpreting the gameplay into a meaningful therapy routine, first it is important to have an understanding of how the game is played. Based on this understanding, then it will be possible to find out what kind of information needed by defining questions usually asked by the users. In the end, visualization requirement elicitation will be done by translating each question into list of tasks. This chapter discusses each one of these steps in details.

2.1 Hammer and Planks Game Dynamics

Played with Kinect, it is possible to play Hammer and Planks in three different ways:

1. BodyTilt Player puts both arm in his/her hips and move the the upper body (from the waist up) to the right, left, forward or backward to navigate the boat.
2. HandPoint Player lifts one of his/her forearm in front of the body with the palm facing forward. Navigating the boat can be done by moving the forearm to the right, left, forward, or backward.
3. ShoulderCGE Player lifts one of his/her arm in front of the body and bend the elbow. Moving the elbow up and down will navigate the boat up and down the screen.

For both the BodyTilt and HandPoint there are three direction available: (i) Horizontal: the screen scrolls from top to bottom and player navigates the ship from left to right (ii) Vertical: the screen scrolls from right to left and player navigates the ship from top to bottom of the screen (iii) Both: the screen scrolls from top to bottom and player navigates the ship from left to right. He/she can also move the boat faster or slower by bending the upper body (BodyTilt) or arm (HandPoint) forward or backward . For ShoulderCGE there is only vertical direction. In this thesis, I only interested in games played using BodyTilt and HandPoint movement for both direction since it provides the information on how fast/slow the boat is moving.

Before each session, the healthcare professionals will set the number of objects (enemies, bonuses, obstacles), activity duration and repetition, as well as area in which the objects can appear. Therefore he can adjust the difficulty of the game for different session.

2.2 Target User Questions

A traditional Hemiplegic therapy routine usually involved the therapist ordering a patient to perform several movement repetitively [19]. By the end of the session, the therapist



(a) BodyTilt

(b) HandPoint

Figure 2.1: Hammer and Planks movement type

will analyse how the patient has performed based on the quality of movement as well as how the patient has progressed compared to the previous session. Based on this analysis, the therapist will then configure a new routine to further the patient's progress, if needed.

However, by using a game to facilitate the therapy, it is difficult to monitor how often the patient has moved his/her arm, to which direction and to which objects this movement is associated. Based on this reason, I identified 5 types of questions usually inquired:

- (Q₁) For a given session, to which direction (right/left) the player moved more?
- (Q₂) For a given session, how does the player perform based on the number of objects collected, avoided, or killed with respect to the area of the movement?
- (Q₃) For a given session, how does the player perform based on the number of objects collected, avoided, or killed with respect to the area of movement and the speed in which the game is played?
- (Q₄) For a given patient, has he/she improved in the game overtime?
- (Q₅) For a given patient, has he/she improved in a certain area overtime?

2.3 Visualization Requirements

The gameplay of each game session is logged in a json file which contains information of the player, game setting, and every events (i.e. enemy killed, bonus collected, etc.) happened in the game. Based on these information and the question defined in the previous section, the tasks can be grouped into: task related to a session for a particular player (Task 1) and task related to the summary of a player which concerns all sessions (Task 2). The following are the tasks defined for each task group:

- (T1.1) visualize and compare the number of events of an event type at a given x area (Q_1)(Q_2).
- (T1.2) compare the number of events for different event type at a given x area (Q_1)(Q_2).
- (T1.3) visualize and compare the number of events of an event type and its screen speed at a given x area (Q_1)(Q_2)(Q_3).
- (T1.4) compare the number of events for different event type and its screen speed at a given x area (Q_1)(Q_2)(Q_3).
- (T1.5) select and visualize the number of events for a certain object at a given x area (Q_1)(Q_2).
- (T1.6) select and visualize the number of events and its screen speed for a certain object at a given x area (Q_1)(Q_2)(Q_3).
- (T2.1) visualize and compare the number of events of an event type among each session for one patient (Q_4)(Q_5).
- (T2.2) compare and navigate the number of events among different event type in a certain x area among each session for one patient (Q_4)(Q_5).
- (T2.3) select and visualize the number of events of a certain event type in a certain x area among each session for one patient (Q_4)(Q_5).
- (T2.4) visualize and compare the distribution of certain number of events of an event type over x area among each session for one patient (Q_4)(Q_5).
- (T2.5) compare and navigate the distribution of certain number of events among different event type over x area among each session for one patient (Q_4)(Q_5).
- (T2.6) select and visualize the distribution of certain number of events over x area for a certain event type among each session for one patient (Q_4)(Q_5).
- (T2.7) extract and visualize similar pattern of number of events over a certain x area and sessions for one patient (Q_4)(Q_5).

CHAPTER 3

Related Works

There has been several serious game for hemiplegic rehabilitation developed in the last few years. Similar to Hammer and Planks, these games also has some visualization feature which shows how the player performed so that the therapist is able to make the correct diagnosis. Thus, in this chapter, I first review some of these visualization. Then, since the nature of the input data is time series and movement data, I present some work in visualization which are related to this type of data.

3.1 Visualization of Serious Game Result

Game result visualization is an integral part of a serious game used for rehabilitation since it's the feature which influence the accuracy of therapist analysis. Most serious game have an analytic feature, however the type of analysis presented depends on the nature of the game and the framework used in the rehabilitation. Therefore, for the purpose of this thesis, I only focus on reviewing serious game which are directed to hemiplegic patients rehabilitation.

In his paper, [19] presents a rehabilitation framework for hemiplegic patients which combines the use of Kinect and LEAP¹ hand-tracking devices. These devices are attached to a 3D based game environment which was set to accommodate a set of primitive therapy motion such as forearm pronation/supination, shoulder and hip joint adduction/abduction, etc. Similar to Hammer and Planks, one of the game used in the framework requires user to navigate a plane by moving the hand to the right and left (hand-elbow flexion-extension). The recorded movement is then presented in line chart depicting the range of axis of elbow joint (180 degrees when fully extended and 20 degrees when fully flexed) over number of frames captured. Similarly, current visualization in Hammer and Planks also uses line chart to show average body movement over time. At first, line chart is used to represent Hammer and Planks gameplay, however in the end this approach is abandon since it's not intuitive enough. Details of this attempt can be found in chapter 4.

In [12], a virtual reality rehabilitation system for children with hemiplegia was developed using TUI². The game itself is displayed on LCD and the player interact with the game by placing the TUI on top of moving targets shown on the LCD. In this system, performances are measured by speed, accuracy and trajectory(mean movement efficiency). However, unlike [19], this system doesn't provide an interface in which therapist can analyse the gameplay.

¹<https://www.leapmotion.com/product/desktop>

²https://en.wikipedia.org/wiki/Tangible_user_interface

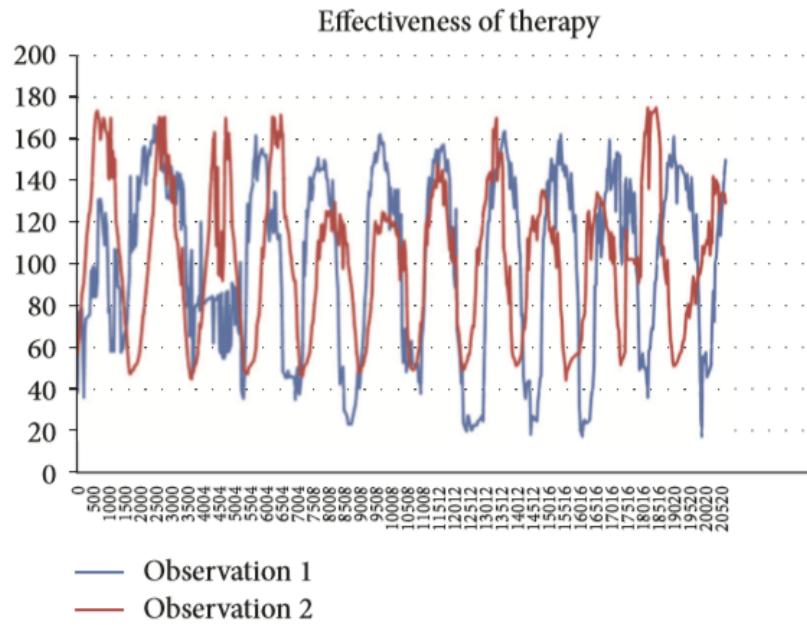


Figure 3.1: Visualization used in [19] depicting the degree of forearm movement overtime

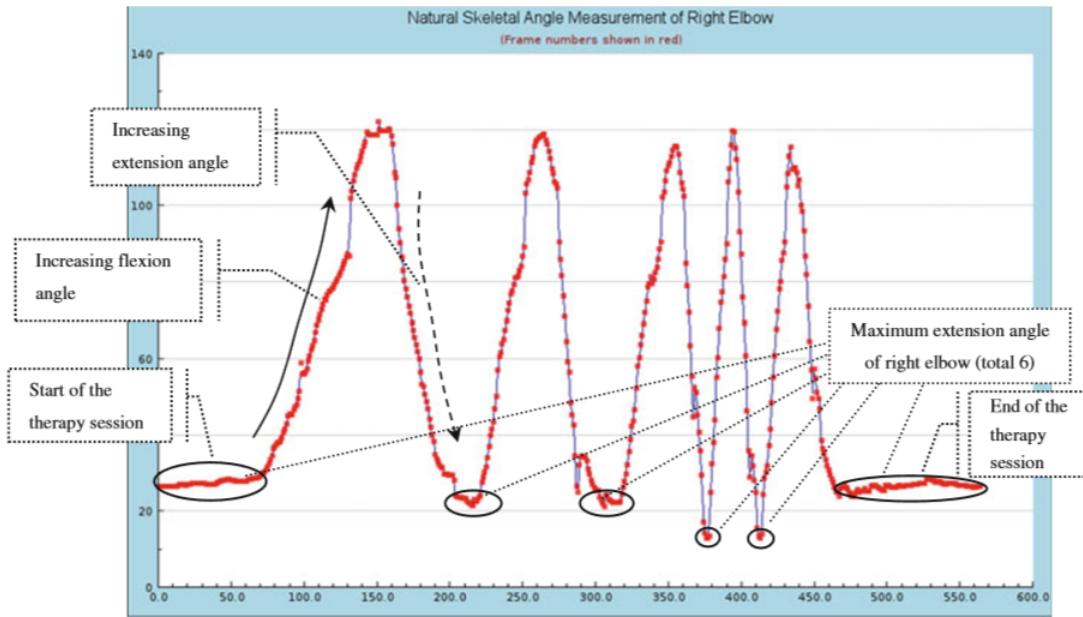


Figure 3.2: Visualization used in [20] depicting the speed of movement (m/s) of forearm overtime

Similar to Hammer and Planks, [20] introduced a framework which uses Kinect attached to Second Life³ serious game environment. The mission of the game is to follow a set of movement that have been configured beforehand by the therapist. During the game, the movement of each body joint is recorded and saved in Session Recorder. Afterwards, a Kinematic Analytic component will process this data and visualize the quality of improvement metrics of each body joint movement. Each metric is visualized with a dotted line chart over time as shown below. Even though it's possible to see which line curve indicate an elbow flexion or extension, the therapist needs to count the number of the curve manually. This is not very efficient when the session is longer and there are more curve to count.

3.2 Visualization of Time Series Data

Since one of the requirement of the interface is to have the information of movement evolution over time, it is interesting to review how a time series data is usually visualize. [1] discuss at length about the techniques of time series data visualization. This section, reviews some of these interesting techniques.

Considering that the recorded gameplay data contains spatial information (location of an event happened on the screen), some of the reviewed techniques are concerning visualizing spatio-temporal data. **Flow Map** depicts movements of object over time. Object movements are usually represented by directed trajectories over spatial space(i.e: map) with different color, width, angle of trajectories represent additional information. In order to overcome overlapping trajectories for huge amount of data, usually aggregation techniques (clustering, self organizing map, etc.) are introduced to group similar data point. Figure 3.3 shows an example of flow map depicting photographers movement between cities in Germany [3]. In this case, the aggregation considers three parameters: initial location, destination location, and time period in which the movement happened. Trajectories width indicate the number of photographers who move between the cities. Another visualization technique worth to mention is **Spatio-Temporal Event Visualization** which uses the space-time cube concept. In this concept, the x and y axis usually represent two spatial dimension while the third axis represent temporal dimension. The events are then represented as graphical objects which are mapped to the space-time cube location. Different events attribute can be represented in different size, colors, shape, or texture. Figure 3.4 shows space-time cube which depict convective clouds [24], human health [23] and earthquake events [10] from left to right. As we can see, the spatial dimension of the left chart is area in pixel while the middle and right chart is a map. The events on the chart are represented with sphere objects with different color and different sizes. Even though space-time cube can portrays the spatio-temporal data, it has some downside. When there are too many events, occlusion is inevitable. It should be coupled with an appropriate interaction technique to allow users see the data from different perspective.

One example of time-series visualization technique which doesn't concern spatial data is Theme River. First introduced in [13], Theme River is used to visualize thematic

³<http://secondlife.com/>



Figure 3.3: Flow Map

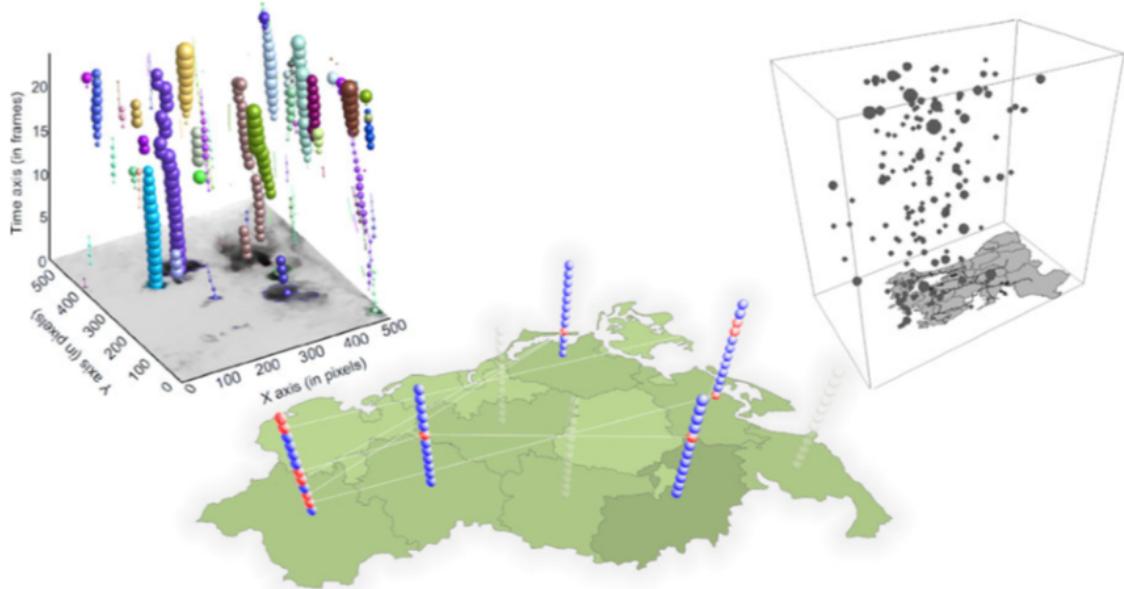


Figure 3.4: Spatio-Temporal Event Visualization

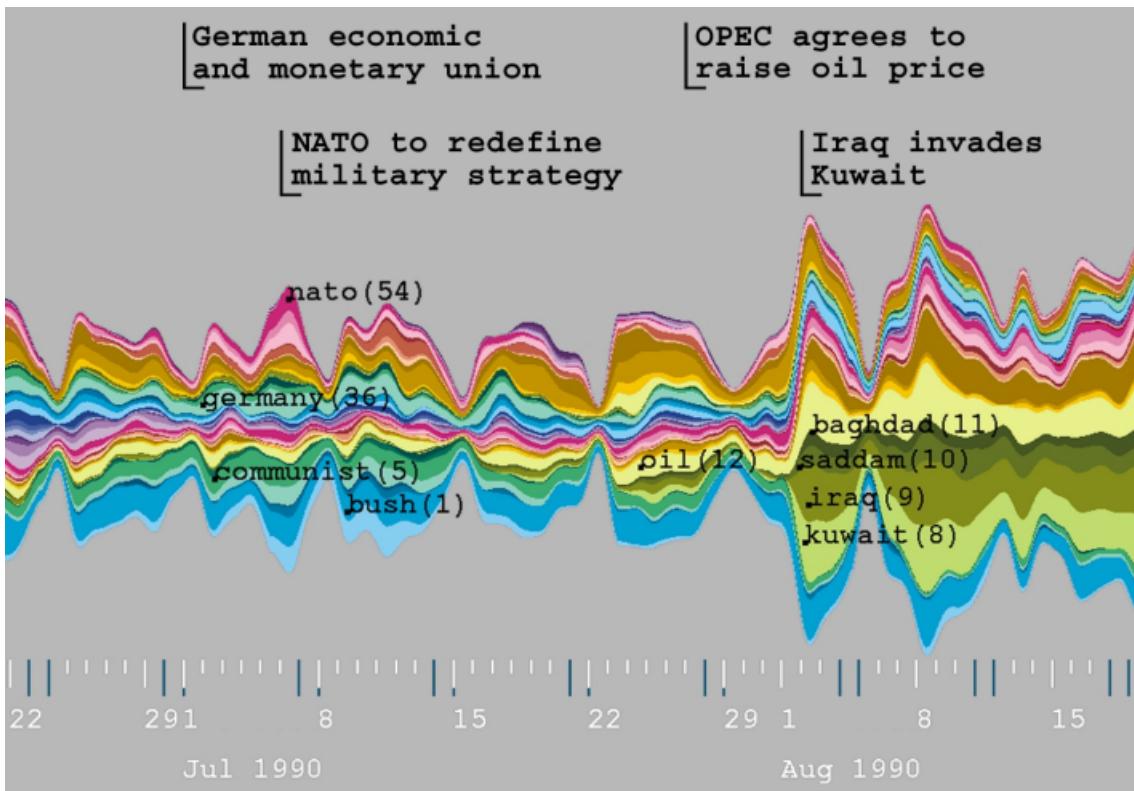


Figure 3.5: Theme River

changes over time of document collection. Each theme is represented as different colors which flows from left to right with different width over different time point. The width depicts theme strength over temporal axis. The purpose of this technique was to easily understand the evolution of theme strength over time. Figure 3.5 shows an example of Theme River representation of 1990 Associated Press newswire data. It can be seen on the chart that the theme baghdad, saddam, iraq, and kuwait are gaining strength around the time Iraq invaded Kuwait on August 2, 1990. By following the flow of a certain color (theme) we can easily see the changes in theme strength and associate it with the events that affects the changes. Theme River should be supported with interaction techniques which allow user to rearrange river positioning over horizontal axis.

Consequently, the Theme River technique is chosen due to its ability to show evolution of a certain data variable over time. Further details on the implementation can be found on Chapter 4.

3.3 Visualization of Movement Data

Movement data usually represents an object which moves over a certain space [2]: data of moving car, birds migration, etc. It's usually recorded as series of location (latitude/longitude, x/y coordinates, etc.) and time. On the other hand, body movement data are recorded as vector representation of human pose [4] over time. On this section, I first review visualization for movement data in general and then discuss visualization for

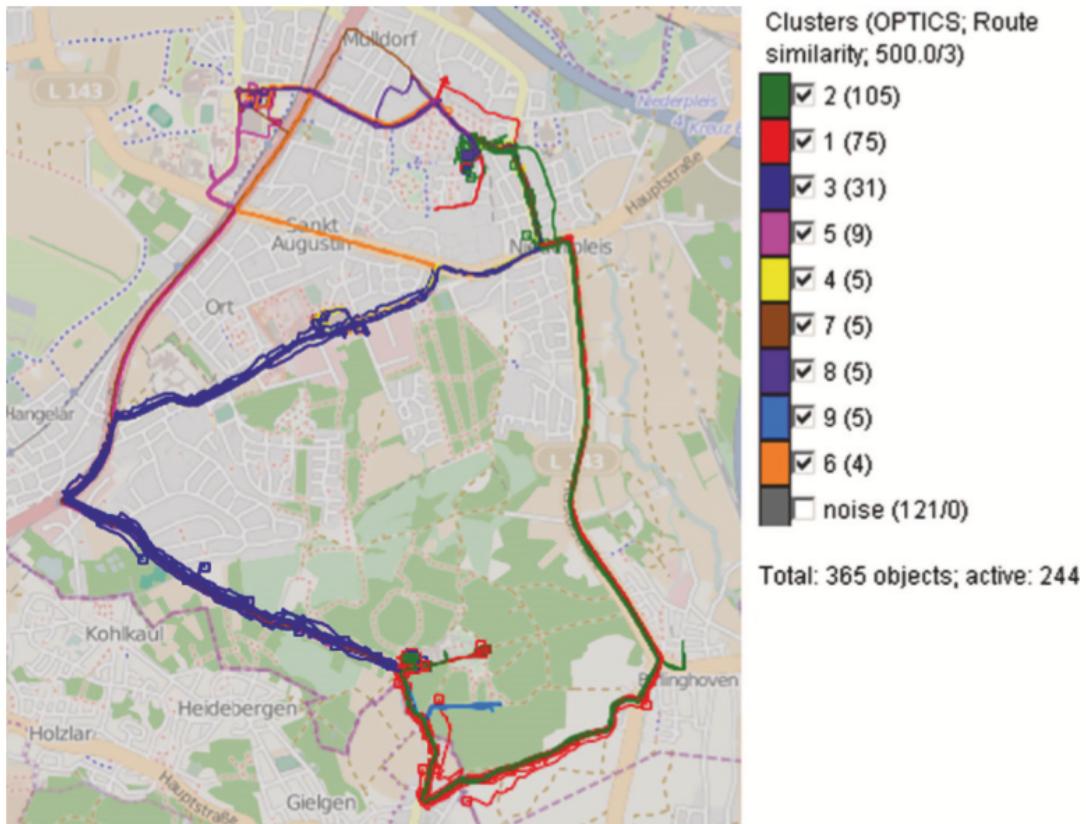


Figure 3.6: Car Trajectories clustered by route similarity

body movement focusing on visualization for skeleton animation⁴ data.

There has been numerous method and application developed to analyse movement data. [3] gives an overview on these methods and applications. Movement data for discrete entities are usually represented as linear symbol over a map or space time cube. However, this technique has problem with occlusions for huge amount of data. Therefore, it's usually accompanied with other graph such as time graph. Other solution to this problem is to use clustering on the trajectories. Apart from minimizing the number of trajectories presented on the view at the same time, clustering also help user to find interesting pattern of the movement. Figure 3.6 [2] gives an example of trajectories of a single car from gps data over several days. The trajectories are divided by stop duration at least 3 hours and clustered by route similarity represented in different colors. Therefore, it is possible to know which route are often or less taken by car owner.

Patterns can also be found by introducing aggregation and generalisation technique on spatial or temporal properties of the movement. For example, the movement data can be aggregated spatially into a discrete grid and for each grid, the number of movement (total or average) happened within the grid can be represented with color or objects in different size. Figure 3.7 [2] shows the presence of cars in Milan in certain geographical area (generated with Voronoi tessellation [17]) during certain time period. The number

⁴https://en.wikipedia.org/wiki/Skeletal_animation

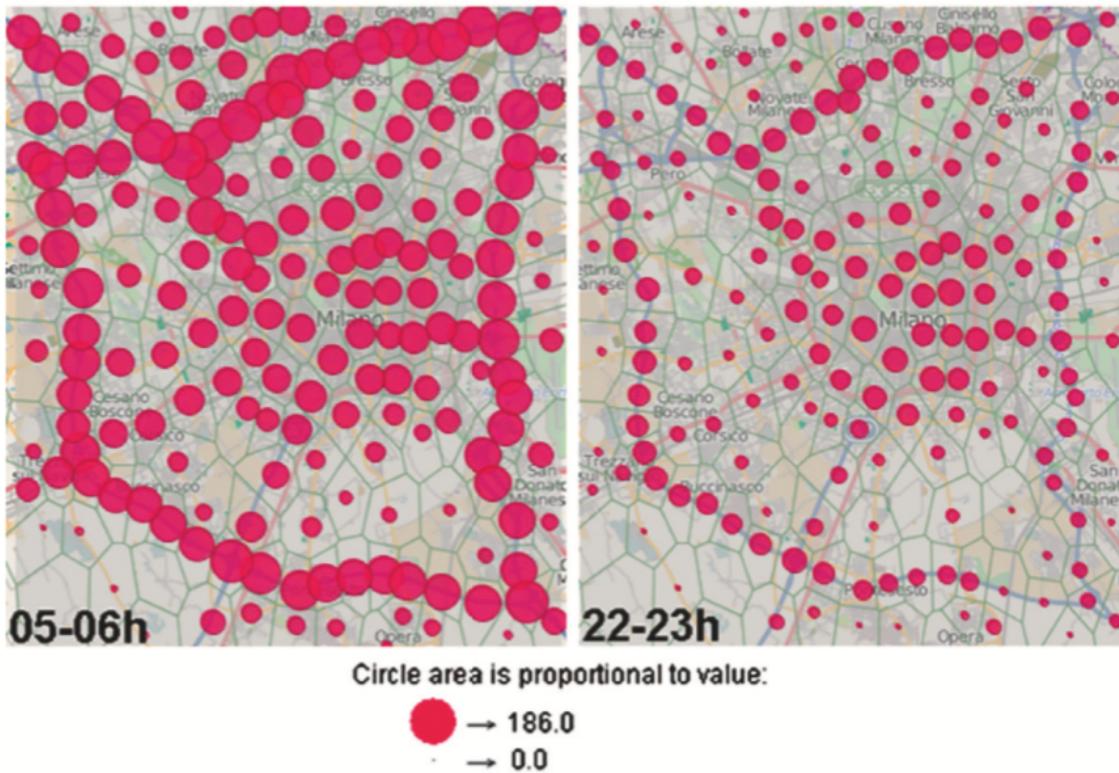


Figure 3.7: Presence of cars in Milan in different time period

of cars in the area is represented with a circle in different size which indicate intensity of traffic. As we can see, there are more traffic between 05-06h (left) compared to 22-23h (right). This is understandable since most people leave work around 5 to 6 pm and are already home at 22-23 pm.

Recognizing and understanding human movement has many benefits in different application domain: arts[14, 21], sports[4], healthcare[18], etc. There are numerous research has been done concerning human movement analysis as discussed in [11] which surveyed different methodologies and approaches. Most of the methodologies discussed focus on identifying a certain type of movement. On the other hand, to my knowledge, there hasn't been many research which focus on human body movement visualization in which user can explore and analyse a certain data set.

[8] proposes a system to track and visualize body movement on a virtual environment in real time. In this system, body parts which desired to be tracked are attached an optical system with twelve infrared cameras. Once user move the tracked body parts, a "motion trail" will be shown in the virtual environment in which then user can manipulate its representation by changing the color, shape, smoothness, etc. These interaction also conducted directly in the virtual environment. Figure 3.8 [8] below shows the motion trail produced in the virtual environment while a user move the tracking device in his hand. On the right is the interface where user can interact with the visualization.

Another approach to visualize body movement is by using color belt [22]. In this approach, movement data collected from motion capture system with 11 sensors attached

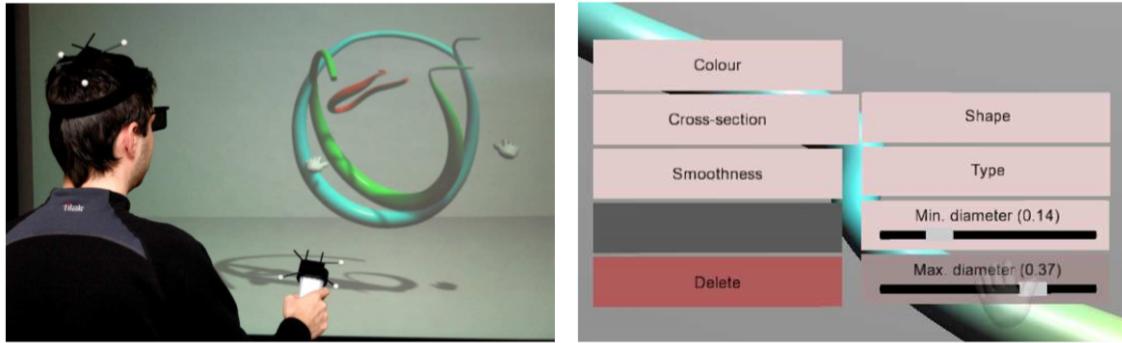


Figure 3.8: Motion Trail

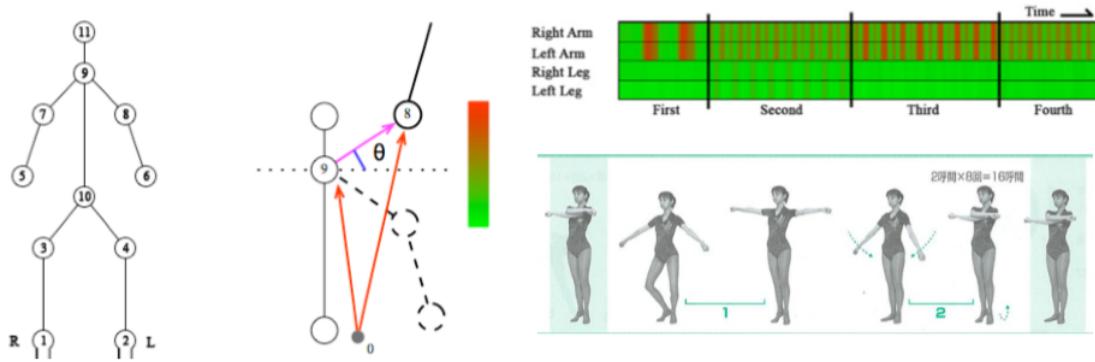


Figure 3.9: Color Belt depicting gymnast body movement

in body joints (Figure 3.9 left) are grouped into 4 limbs movement: Right Arm, Left Arm, Right Leg, Left Leg. Each of the limb representation is arranged in vertical axis sequentially forming a belt. The horizontal axis represents time (from left to right) and the sections represent sets of movement. Limb motions are shown as gradation of red-green colors in this belt by extracting the position and angle of associated body joints data (Figure 3.9 middle). Positive angle is represented with red color, while negative angle is represented with green color. Figure 3.9 (right) shows a color belt and how it is related to the body movement done by a gymnast. The color belt shows the first to fourth movement set. As can be seen in the picture, the gymnast move her leg on the second exercise and the second section on the color belt depicts the movement for right leg and left leg.

MotionExplorer[4] introduced human motion exploratory search using hierarchical aggregation. This approach are directed towards the need to explore huge quantity of motion data and be able to identify interesting sequence of movements. Implemented on database which contains various motions in multiple repetitions, first each human pose data is clustered using k-means algorithm. A pose cluster comprises of a large numbers of similar human pose and is represented as a circular glyph with human stick-figure pose as the centroid and set of pose in the cluster as deviating, transparent figures. The cycle around cluster glyph are colored based on color legend and shows similarity among clusters. MotionExplorer provides 4 views (figure 3.10): (i) *Pose hierarchy explorer* (top left) allows user to explore all available pose cluster in the data sets hierarchically. The pose cluster



Figure 3.10: MotionExplorer interface

hierarchy is shown as a dendrogram and calculated with a divisive clustering algorithm. The aggregation level is adjustable. (ii) *Motion explorer* (top right) shows sequences between pose clusters at current aggregation level. Human poses are represented as nodes while edges represent motion sequences. Two nodes are connected if there is at least one motion sequence which connects both pose clusters. (iii) *Motion search* interface (bottom right) allows user to input query for a specific motion sequence by inputting start pose and end pose. An interactive search result is provided where user can explore each style variations. The interface is divided into 4 parts: start pose field, search result field, end pose field and pose bundle animation. A user can make search query by choosing/dragging a pose cluster to the start and end pose field. The resulting motion sequences are then shown in the search result field on the granularity of a single human pose. (iv) *Pose color mapping* (box on bottom left) is a color legend related to each pose cluster. The color grid is built using SOM algorithm trained with all feature vectors in a vector quantization scheme. By clicking one of the clusters in the color legend, the aggregation level will be adjusted to the granularity level of the selected pose cluster. Each visualization window is linked. When user changes the aggregation level in the pose hierarchy explorer, the motion explorer is automatically adjusted to the new aggregation level. When user clicks on one of the clusters in the color legend, the system automatically adjust the aggregation level to the same granularity of the selected cluster. If a cluster in one of the view is selected, then the same cluster pose is also highlighted in every view.

3.4 Data Visualization Tool

The popularity of data visualization has been supported with the development of a lot of data visualization tool. To support the development of the interface in this thesis, the survey is focused on tools which allows creation of different visualization technique without restriction of a ready made template or certain chart type.



Figure 3.11: Some of visualizations developed with D3.js

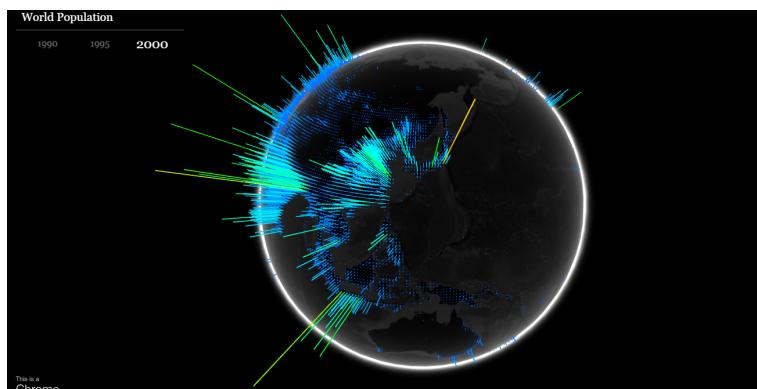


Figure 3.12: 3D visualization of world population developed in Three.js

One of the tools surveyed is D3^[5]. **D3** or Data-Driven Documents is a javascript library which allows user to create desired visualization either the standard one (bar, line, scatter plot, etc.) or the customized one (limited only by one's creativity) in 2D. Built by incorporating HTML5, CSS, and SVG standards, D3 enables user to load data in various format(.json,.csv,.txt, etc.)⁵ and present it as a chart. The various functionality offered by D3 and its detailed API documentation has encourage a lot of people to explore it. This resulted in numerous amount of D3 demo online which can be a good reference source for new user⁶.

Another interesting visualization tool reviewed is Three.js. Similar to D3, Three.js is a javascript library. However, Three.js is aimed to provide support for 3D visualization-with minimal complexity⁷. The features⁸ offered by Three.js allows user to develop 3D visualization on WebGL supported web browser without having to install any third party application. Shown in Figure 3.12 visualization of world population on a globe. User can turn the globe around to explore certain area of the world.

Considering the visualization requirement identified in the previous chapter as well as the features offered by D3, consequently D3 is chosen as the tool for interface development.

⁵<https://github.com/mbostock/d3/wiki/API-Reference>

⁶<http://techslides.com/over-2000-d3-js-examples-and-demos>

⁷<https://github.com/mrdoob/three.js/blob/master/README.md>

⁸<https://github.com/mrdoob/three.js/wiki/Features>

CHAPTER 4

Data Abstraction

In this chapter I discuss the design of data structure and clustering technique used to support the visual requirement. First, an overview of the input data generated from the game will be explained. Then a description on how this data is extracted to be the input of the visualization interface will be given. Finally, a clustering algorithm selected to be used in the visualization will be discussed.

4.1 Game Events Structure

4.1.1 Event Category

The goal of Hammer and Planks game is to kill all of the enemies while avoiding any attack from the enemies and obstacles[9]. Along the way, player can also catch bonuses to increase their score. Based on these, I identify three different objects within the game: Enemy, Bonus, and Obstacle. For each of these object, there are certain events associated. Each event which happened during the gameplay is recorded in the log file with the following information: event type, timestamp, object id, and location. In total, there are 8 event types:

- (1) Catch: when a bonus is caught
- (2) Miss: when a bonus is missed or player's attack on enemy is missed
- (3) Dodge: when an obstacle is avoided
- (4) Collision: when the player's boat collide with an enemy or obstacle
- (5) Kill: when an enemy is destroyed by player's boat
- (6) Hit: when the player's attack hit an enemy
- (7) Hurt: when the enemy's attack hit player's boat
- (8) Miss: when the enemy's attack missed player's boat

Based on the level of impact of each event to the user's boat, we characterize the event by assign it with Positive, Neutral, or Negative as shown in the following table:

4.1.2 Game World Coordinates

Each object and event in the game are assigned with 3D location coordinates. An x axis of this coordinate indicate horizontal axis of the screen. However, y axis indicate vertical axis in the game world which means $-y$ is a location under the sea and $+y$ is above the sea.

Events	Bonus	Obstacle	Enemy
Positive	catch	-	kill, hit
Neutral	miss	miss	dodge
Negative	-	collision	hurt, collision

Table 4.1: Event Type grouping

z axis indicate vertical axis of the screen. The visualization uses the x axis to represent body movement over horizontal axis and z axis to calculate screen speed as explain in the following sub section.

4.1.3 Screen Speed

In the game, a big number of positive events indicate a good player's performance. However, it is important to consider whether the events happened when the player's boat move fast or slowly (*T1.4*) (*T1.6*). Getting all the bonuses while moving fast requires precise hand/body movement which indicates improvement in rehabilitation process. Boat speed while navigating the sea is basically the speed in which the screen scroll(v_{scr}). This is calculated by identifying the location(apparition z coordinate θ_{apr}) and time (apparition time t_{apr}) of an object when it first appear on the screen, and location(event z coordinate θ_{evt}) and time(event time t_{evt}) when an event happened on that object.

$$v_{scr} = \frac{\theta_{evt} - \theta_{apr}}{t_{evt} - t_{apr}}$$

4.2 Clustering Algorithm

In understanding the common evolution of the gameplay among different sessions over x -area, it is interesting to see what the common evolution of different section of x -area (*T2.7*). The idea is to aggregate similar distribution of movements (which is represented by events in the game) so that consecutive section which has similar evolution is represented by a single representation. To achieve this, a clustering algorithm based on hierarchical clustering is introduced:

Algorithm 1 Hierarchical Clustering

- 1: Divide the x-area into slices the size of selected x range.
- 2: Define the profile for each section. Let a section be Slice S_i , number of session be n_{ses} and number of section be n_{sec} . An S_i is an ordered set of triplet t_i . Each triplet represents dataset of a certain game session of a particular Slice. The triplet consists of the number of negative, neutral and positive events.

$$t_i = (n_{neg}, n_{net}, n_{pos})$$

$$S_i = \{t_i(1), t_i(2), \dots, t_i(n_{ses})\}, 1 \leq i \leq n_{sec}$$

- 3: Normalize each slice by dividing each triplet component with max triplet value max of S_i .

$$N(S_i) = \left\{ \left(\frac{n_{neg}}{max}, \frac{n_{net}}{max}, \frac{n_{pos}}{max} \right), \dots, \left(\frac{n_{neg}}{max}, \frac{n_{net}}{max}, \frac{n_{pos}}{max} \right) \right\}$$

- 4: Calculate the distance between slice S_i and S_{i+1} using Euclidean Distance.

$$d(S_i, S_{i+1}) = \sum_{j=1}^{n_{ses}} ED(t_i(j), t_{i+1}(j))$$

- 5: Following the Hierarchical Clustering algorithm[15], merge two consecutive slices if it satisfies the distance threshold specified beforehand. Calculate the distance of the merged slices with the next slice and merge them if the distance is still below the threshold. Repeat the process until there is no distance which satisfies the threshold.

CHAPTER 5

Visual Mappings And Interactive Functionality

This chapter describes different visualizations and interaction methods developed based on the visualization requirements and data abstraction discussed in Chapter 2 and 4. In general, the visualization is divided into two parts: Session visualization which visualize movement in one particular session and Summary visualization which visualize movement over different sessions. Both visualization is organized in an application where user can select player and sessions he has played. At first, the earlier version of visualization will be explained. This earlier version is not used in the final version since it's difficult to get any information intuitively. Then, each type of visualization and its interaction used in the final version will be discuss. In the end, the application which encapsulate both visualization will be presented.

5.1 Early version of the Visualization

The first visualization method chosen to represent (*T1.1*) and (*T1.2*) is line chart. In this approach, the x area is shown as a horizontal axis and the number of events shown in vertical axis with the line signify the changes of number of events for different x area unit. In the log file, each event is recorded with distinct 3D coordinate location. The x value from this coordinate is a decimal, therefore visualizing each one of this x value will require a lot of space. To solve this, the events are then grouped by the rounded x value. In figure 5.1 below, Negative events are shown in red line and Positive events are shown in blue line. As we can see, it's possible to know which event type happened more in a certain x unit, however it is difficult to see how big a percentage is it compare to total number of events happened in the same x unit.

Visualization method chosen to represent (*T1.3*) and (*T1.4*) is scatter plot. At first, each event type is presented in three different chart area: top are for Positive events, middle are for Neutral events, and bottom area for Negative events. Similar to the line chart, the x value from the 3D coordinate location are represented in horizontal x axis. However, the vertical axis here represent the screen speed. For the scatter plot, each event

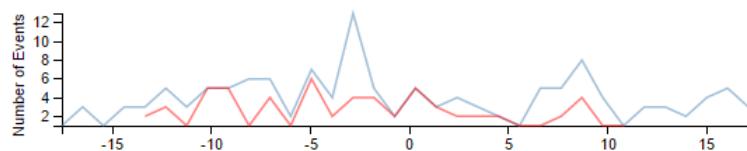


Figure 5.1: First visualization version for (*T1.3*) and (*T1.4*) using Scatter Plot

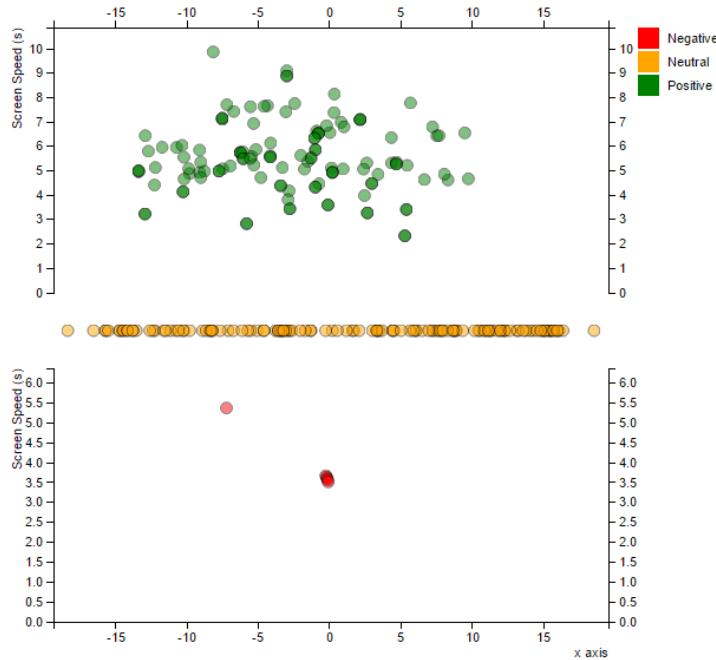


Figure 5.2: First visualization version for (T1.1) and (T1.2) using Line Chart

is shown as a plot in the chart area according to it's x value and screen speed as shown in figure 5.2. Even though similar pattern can be seen on the scatter plot, occlusion problem prevent users to know how many event are actually happened in a certain x area.

5.2 Session Visualization

The Session Visualization visualizes events within a game session. Basically, the requirement can be split into two: (i) knowing the distribution of events and movements (ii) knowing the distribution of events, movements and screen speed. Therefore, there are two chart developed to meet these requirements: stacked area for (i) and heatmap for (ii), each of which will be explain in details in this section.

5.2.1 Stacked Graph

Build on layered area graph, Stacked Graph is widely used to visualize evolution of variable over times such as document theme [13], box office movie revenue¹, listening history in Last.fm [7],etc., Stacked Graph is chosen because its ability to show individual value of a variable, the difference between values of different variables as well as the total of overall value. In my approach, instead of using this metaphor to show evolution over time, it is used to show distribution of events over spatial coordinate (T1.1)(T1.2) as shown in figure 5.3. Here, the horizontal axis represents x coordinate and vertical axis represents number of events. Each event type is represented as an area with different color: Red

¹http://www.nytimes.com/interactive/2008/02/23/movies/20080223_REVENUE_GRAPHIC.html?_r=0

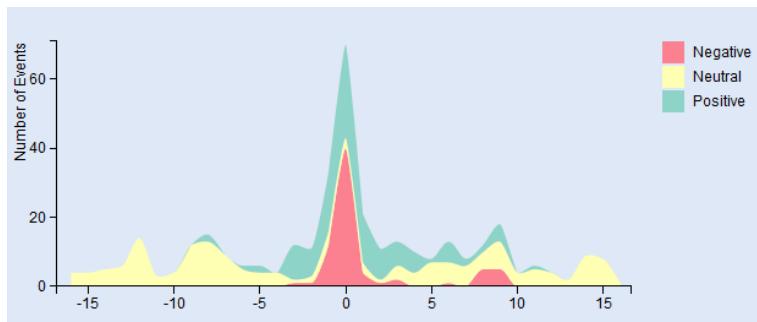


Figure 5.3: Stacked Graph with Linear Layout

(Negative), Yellow (Neutral), and Green (Positive). To help user understand better the distribution of each event type, different layout of stacked graph is provided:

1. Linear: zero y axis is used as the baseline, with the stack ordered from bottom as negative, neutral, positive.
2. Silhouette: the graph is centered as in streamgraphs.
3. Positive: zero y axis is located at the top of the chart and is used as the baseline with the stack ordered from top as positive, neutral, negative.
4. Neutral-Negative: zero y axis is located in the middle of the chart. Neutral and Positive event is shown on the positive area of y axis and Negative is shown on the negative area of y axis.
5. Positive-Neutral: zero y axis is located in the middle of the chart. Positive event is shown on the positive area of y axis, while Neutral and Negative is shown on the negative area of y axis.

For each stacked graph layout, user can choose which object type to show on the graph (*T1.5*). Options are available as radio button on top of the chart. Therefore, choosing Bonus will show only Positive and Neutral events, choosing Obstacle will show only Neutral and Negative events, and choosing Enemy will show all event type.

5.2.2 Heat Map

Heat Map is a quite popular visualization method nowadays due to its ability which allows user to see variable with the highest value at one glance. Most of the time, heatmap is implemented on geographical map to represent variable value over certain area on map, i.e: Natural Disaster Risk by Location², population density³, Number of picture taken in an area⁴, etc. Heat map is also used to track eye movement or mouse click on a website, and representing DNA microarray data in the form of cluster heat map[?]. Heat map uses color gradation to represent the hotness level of a variable. Usually, red color is used to represent the high value (hot) and blue is used to represent the low value (cold). However,

²<http://www.rms.com/>

³https://en.wikipedia.org/wiki/Population_density

⁴<http://sightsmap.com/>

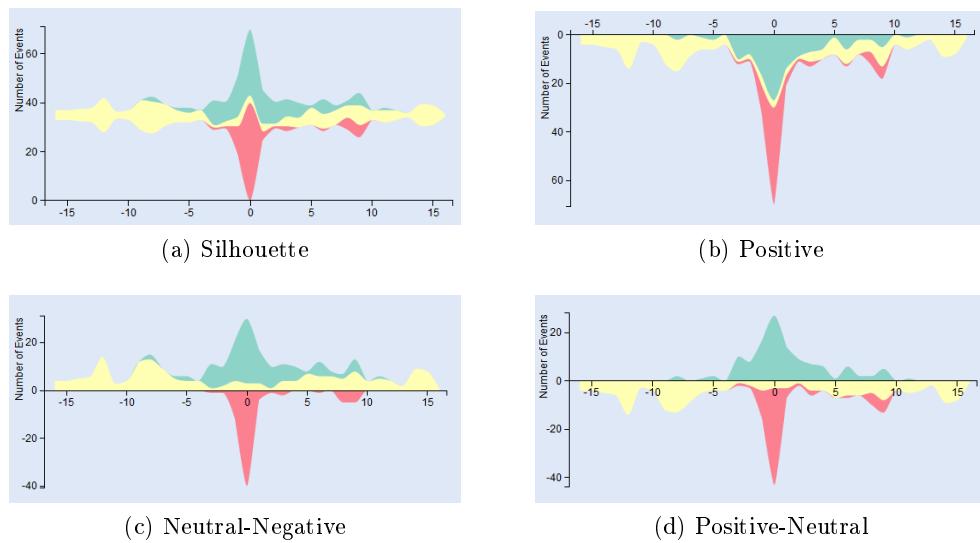


Figure 5.4: Different Layout of the Stacked Graph representing number of events over x-axis

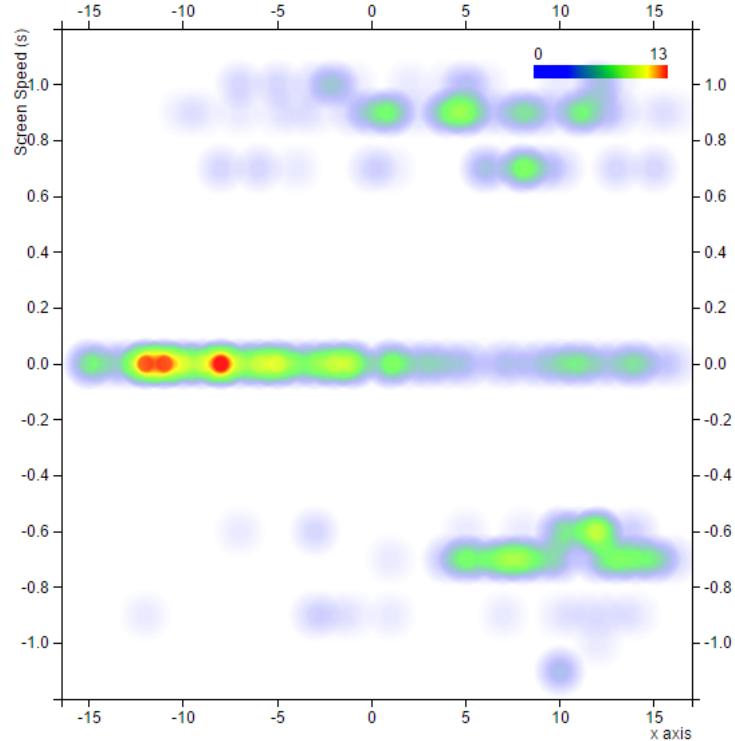


Figure 5.5: Heatmap

other color combination can also be used. To represent distribution of events and screen speed over x axis ([T1.3](#))([T1.4](#)), the events are first grouped based on it's x value and normalized screen speed. The number of events is then represented as heat map on the graph with highest number of events in red color. Normalized screen speed is represented as vertical axis and x value is represented as horizontal axis. Using the same approach used in scatter plot chart, each event type is presented in different area: top for positive, middle for neutral, and bottom for negative. For Neutral events, the screen speed is not calculated since it basically mean an object has been avoided or missed. For Negative events, the screen speed is represented in negative to show that it's an uncalculated movement. For the heatmap, user can also choose to show a specific object ([T1.6](#)) by clicking the radio button associated with the desired object.

5.3 Summary Visualization

The Summary Visualization fulfills the requirements concerning movement evolution over time ([T2](#)). In this case, a single session is considered as a single time point. Since user are interested in evolution over a certain x-area, the visualization are divided into sections of x-area. There are two ways of division: by the range of x-area and by the number of events within an area. The following explains the two approach and its interaction technique in details.

5.3.1 Visualization by range of x-area

To fulfill ([T2.1](#)) and ([T2.2](#)), a streamgraph metaphor is chosen to show evolution of movement (represented by events) over time. Similar to the approach chosen in the Session visualization, the horizontal axis represent x coordinates of events. The vertical axis represent different sessions with the earliest one shown at the bottom and the latest one shown on the top. The x axis is then divided into sections of the same range based on user input. For each section, events are then filtered to the one which happened within the section x boundary. The filtered events are grouped based on session number and event type. Number of events within this group is then presented in vertical streamgraph layout with event type represented using the same color used in the Session visualization ([Figure 5.6](#)).

Shown in figure [5.8](#) a section in the chart. Here, the lower x boundary is -20 and the upper x boundary is -7.33. Within this area, the evolution of events throughout all session can be seen([T2.2](#)). It is also possible to see which session has the most or least number of events by comparing the total length of all event type in one session.

By default, once a user input the desired x-range, the clustering algorithm as explained in Chapter 4 is applied([T2.7](#)). Thus it is possible that the number of sections shown in the visualization are fewer than initially inputted. Shown in figure [5.7](#) a clustered version of figure [5.6](#). Here the first and last two sections are merged into one section. Such the case with the three sections in the middle.

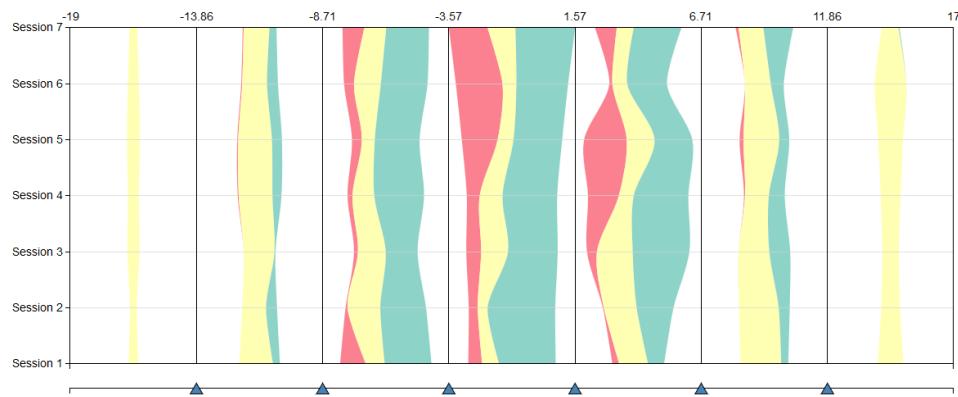


Figure 5.6: Summary Chart divided by range of x-area

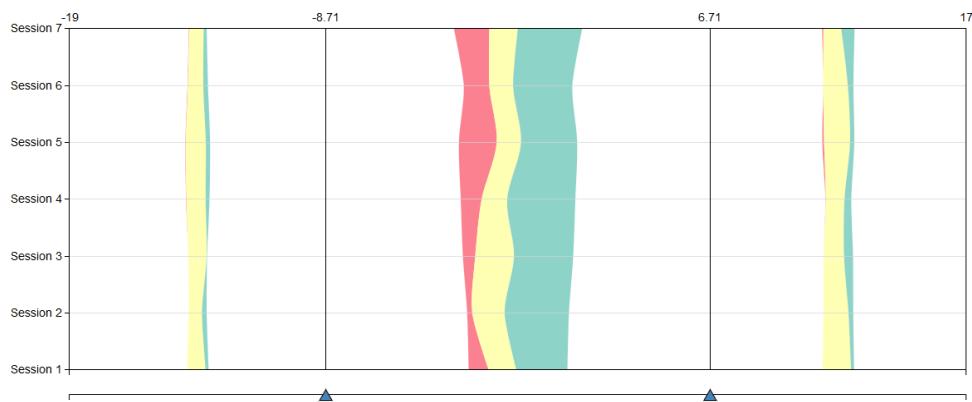


Figure 5.7: Summary Chart divided by range of x-area, clustered with threshold = 4

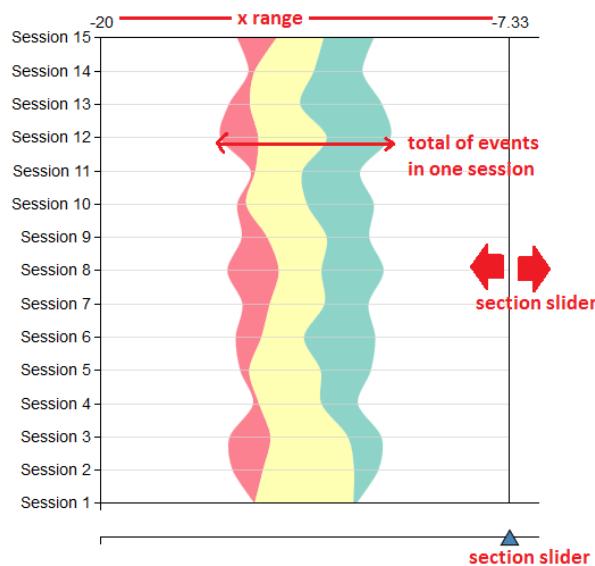


Figure 5.8: A section in Summary Visualization

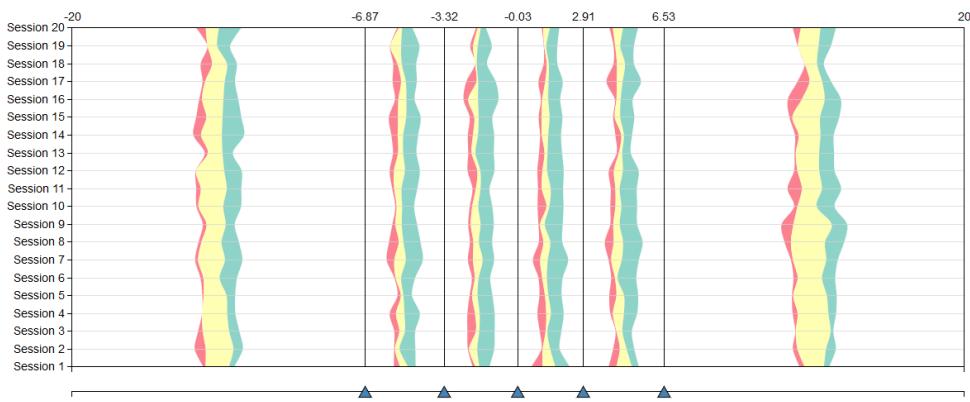


Figure 5.9: Summary Chart divided by number of events

5.3.2 Visualization by number of events

This second type of Summary Visualization uses the same approach explained previously. However, a section is calculated based on the total number of positive and negative events instead of the range of x-axis ([T2.4](#))([T2.5](#)). Therefore, based on the distribution of positive and negative events, one section in the chart may have bigger x-range than the other section. Only by comparing the size of sections, it's possible to know in which area most of the events are concentrated. Figure 5.9 shows that the events are more concentrated in the middle area of the screen. Here, it can be concluded that on the far right and far left of the screen, there are more neutral events compare to the middle area.

5.3.3 Interaction Technique

On top of the chart, an interaction bar is provided where user can interact with and change some variable in the chart. In the first panel of the interaction bar (figure 5.10), a slider which serves two function is provided. First, as an x-range input, second as a number of events input. This two functions can be activated by turning the switch on/off. When the switch is ON, the slider will act as an x-range input. The value on the slider basically define the number of sections on the chart. The more number of sections, the smaller the x-range. When the switch is OFF, the slider functions as a number of events input. In this case, the value selected on the slider is a denominator. The input is calculated by dividing total number of all positive and negative events by the value selected on the slider. Thus, the smaller the number chosen on the slider, the bigger the number of events. In the second panel, user has the options to choose which event type to show on the chart. This fulfills requirement ([T2.3](#)) and ([T2.6](#)). By default all event type will be shown. The third panel provides the option to turn on/off the clustering algorithm and to set the threshold value.

Once the chart is generated, the user has the ability to slide/drag the line between each session (or the small triangle at the bottom of the line) to the right or left to change the range of it's neighbouring sections([T2.2](#))([T2.5](#)). While dragging, the text on top of the line changes based on the current x value of the dragged line. When a line is dragged over another line, the two sections will be merged creating a new section with different



Figure 5.10: Interaction Bar for Summary Visualization

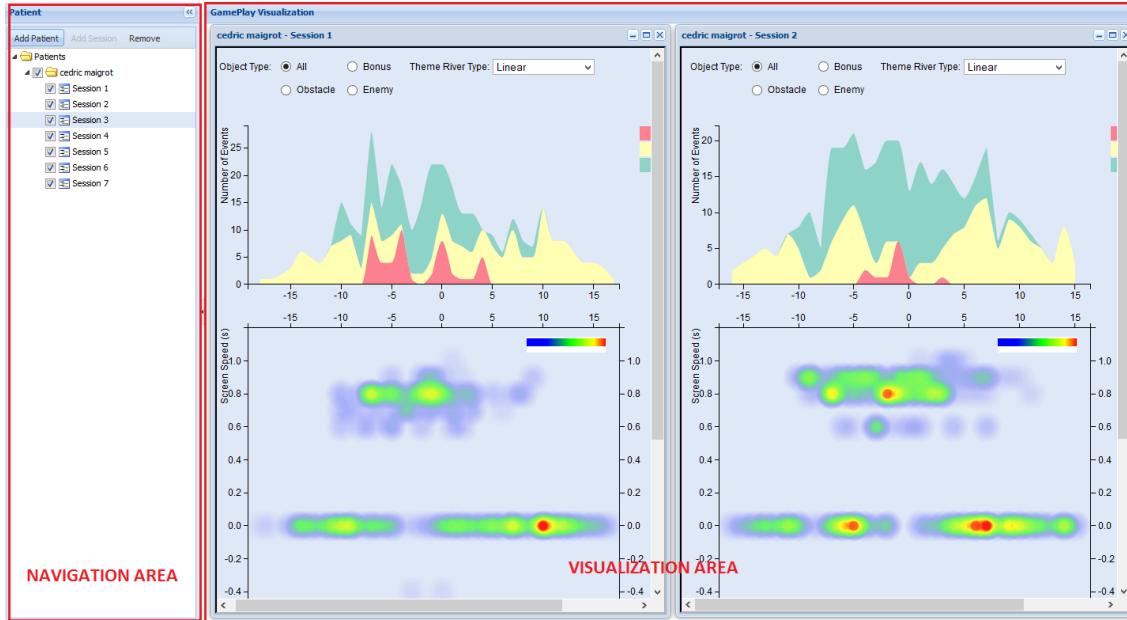


Figure 5.11: Application Interface

x range. Therefore, user may be able to gain the information in which particular area a certain type of events starting to happened. It is also possible to divide a section into two sections by clicking the top area of the chart in between the lower and upper section boundary text. This allows user to know the distribution of event type within a section.

5.4 General Interface

Both the Session and Summary visualization are attached into an application which allows user to navigate different player and session. The interface of this application is divided into two areas: Navigation area and Visualization area (figure 5.11). In Navigation area, user can choose patient and the sessions they have played. On clicking a session, a Session visualization of this session will be shown on the visualization area. It is also possible to open more than one Session visualization and rearrange the visualization window to compare gameplay between sessions. On clicking patient's name, Summary visualization for the chosen session will be shown.

CHAPTER 6

Case Studies

To evaluate the visualization functionality developed in this thesis, two case studies will be presented. There are two types of data collected: log files from healthy person who played the game and log files from patient. The log files from healthy person are gathered in duration of three weeks with each session played in different day. The patients' data are collected by NaturalPad¹. Unfortunately, it is not possible to get information concerning patients' pathology due to confidentiality reason. For figures referred in this chapter, please see Appendix A.

6.1 Case Study 1: Normal Player

The first case study is based on log files of game played by my colleague over the course of three weeks. In total, there are 20 sessions of BODYTILT game collected. Figure A.1 presents a comparison between the very first and last session played by the player. It shows that in the first session, there are a lot of events missed (yellow area) on the far right and far left of the screen which indicate that the player doesn't move her body to that extent. From the peak of area between 0-5 x axis, it can be concluded that the player moves more to the right. The green and red area which indicates positive and negative events only appears around -10 to 10 x axis which indicates that player only moves around the middle of the screen(T1.1)(T1.2). It is understandable for first session because usually player needs time to get use to the game and get the feeling of how far he/she should move his/her body to reach/avoid an object. On the other hand, in session 20, the peak of the area are more spread out and there are even green area at the far right(T1.1)(T1.2) which indicates that the player is able to move to that extent. It seems that the player already has the feeling of how to play the game.

At first glance on Figure A.2, it is noticeable that there are more spot on the top part of the right heatmap (positive events) and less spot on the bottom part of the right heatmap (negative events). It also can be concluded that the player is able to control the boat well on the right chart since there are less spot with high speed of the negative events(T1.3)(T1.4). Which means that the player are getting better on playing the game.

Focusing on events for Enemy as shown in figure A.3, at a glance we can see that there are more negative events and very little positive events on the first session. While on session 20, there are less negative events and more positive events(T1.5). This supports the conclusion made previously that the player has gotten better performance over time. Similar notes are depicted by figure A.4. Here, on the right heatmap, there are more negative events which happened at faster screen speed(T1.6). This supports the fact that

¹<http://www.naturalpad.fr/>

first time player are usually confuse on which direction to move their body/hand to make the boat go faster or slower.

The summary of all the session can be seen in figure A.5. As we can see, the number of positive events are steadily increasing though fluctuate (T2.1)(T2.2). On session 19, there are very small number of negative events on all sections which indicate an improvement in the gameplay. In figure A.6, we can see the evolution of the positive events (T2.3). Overall, the number are steady except for a certain session. However, on the right most section there are some positive events can be found which indicates that overtime, the player move more to the right. On the clustered version of the chart (figure A.7), three sections in the middle are merged together since it shows similar evolution (T2.7). From figure A.8 we can conclude that the movement are more concentrated in the middle area of the screen [(T2.4)(T2.5)(T2.6)].

6.2 Case Study 2: Patient

The second case study is based on log files of game played by Patient 6. There are 15 sessions which are played over the course of three weeks. However, these sessions are of two game type: HANDPOINT (6 sessions) and BODYTILT (9 session). For this case study, only the sessions of HANDPOINT exercise will be discussed. The game for this patient is set to show only obstacles and bonuses.

Focusing on the second session of HANDPOINT (session 10 of all sessions) shown in figure A.9, it can be seen that the positive and negative events only appear on the right half of the chart indicating that the player only move to the right (T1.1)(T1.2). The yellow area are bigger compared to the green and red areas, showing that there are a lot of missed/avoided objects. From figure A.10, we can see that there are many neutral events on the left side of the screen. While positive and negative events are happened only on the right side with similar screen speed indicating that the player didn't change the pace of the game (T1.3)(T1.4). Figure A.11 and A.12 shows events related to bonus (T1.5)(T1.6). Therefore, there are only positive and neutral events. Here, it can be seen that on the far right, there are no bonus is missed, however, on the left side all bonuses are missed. Based on these charts, we may conclude that the player has some difficulty to move to the left. It's important to see if this is an isolated case or happened all the time. Therefore, we need to see the pattern of movement for all sessions which will be discussed shortly.

The summary visualization shown in figure A.13 confirmed that for 4 sessions, the player only move to the right side. If the -2.29 line is dragged to the right, the red and green area only appears from -1.96 boundary. However, from the fifth sessions, there are movements on the left side indicated by a small number of negative and positive events (T2.1)(T2.2). Figure A.14 shows the evolution of neutral events (T2.3). Here, we can see that there are more neutral events on the left side compared to the right throughout all sessions. The clustered version of figure A.13 shown in figure A.15 shows that there are only two movement pattern: on the left side where there are mostly neutral events and on the right side where there are positive and negative events (T2.7). Consistent with all the previous visualization, figure A.16 shows that the movements are concentrated more on the right side [(T2.4)(T2.5)(T2.6)].

Movement of person with pathology are highly affected by the type of pathology. On the second case study, throughout all sessions the movements are concentrated to the right side with almost no movement on the left side. Therefore we can assume that the patient has his left side of the body affected. While for normal person, the movement are more spread out on both left and right side with more concentration in the middle.

CHAPTER 7

Conclusion

In this thesis we presented ... what has been discussed problem and user requirement
proposed approach and what it can do
future improvement

APPENDIX A

Appendix Case Studies

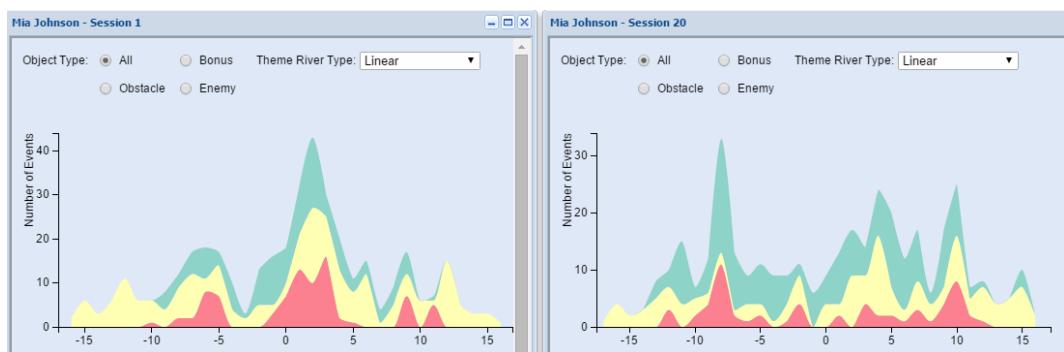


Figure A.1: Stacked Graph comparison of Session 1 and Session 20

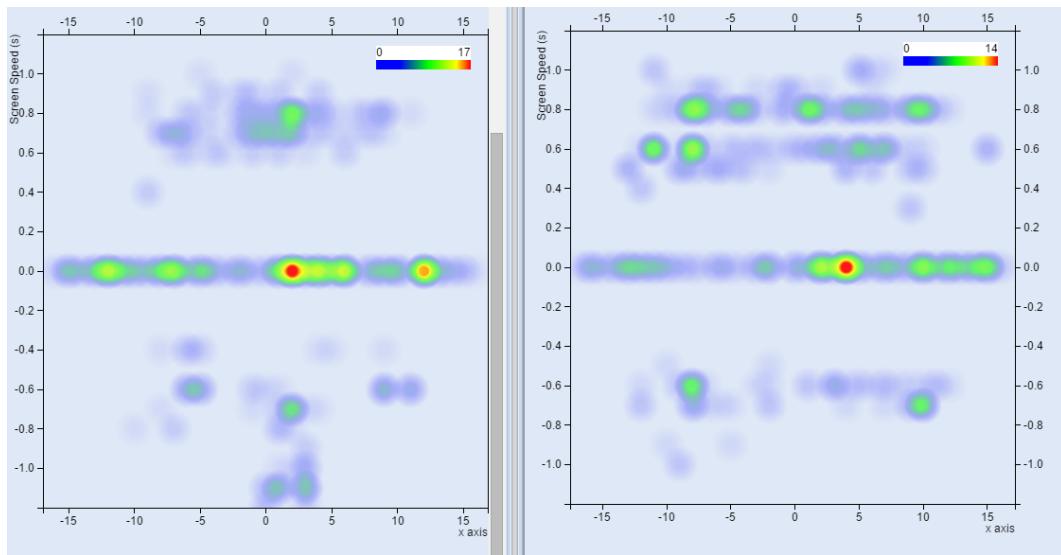


Figure A.2: Heatmap comparison of Session 1(left) and Session 20(right)

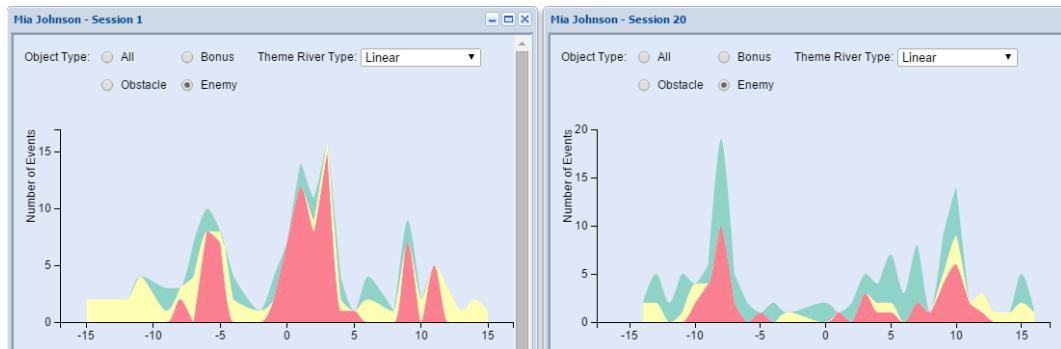


Figure A.3: Stacked Graph comparison of Session 1 and Session 20 for Enemy

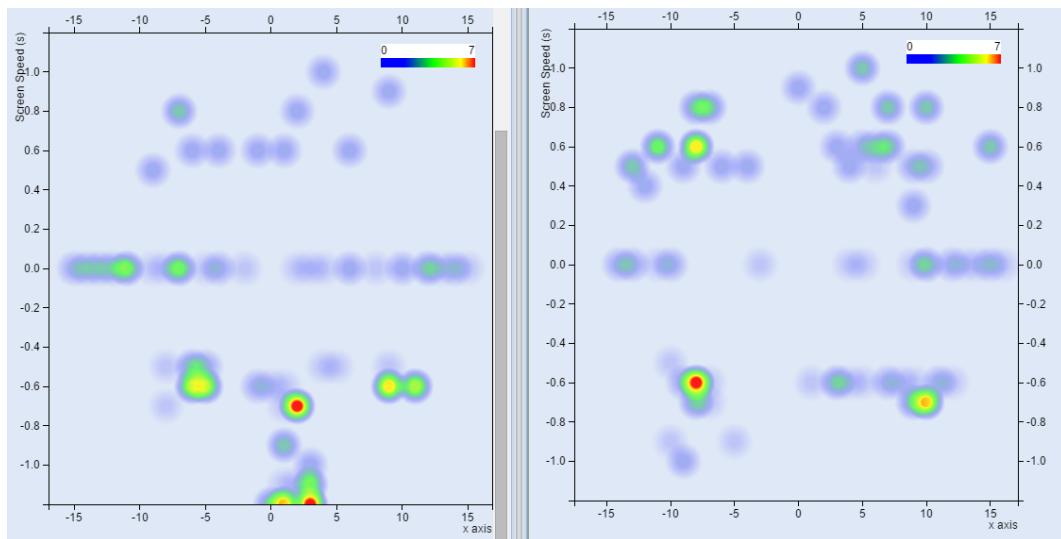


Figure A.4: Heatmap comparison of Session 1(left) and Session 20(right) for Enemy

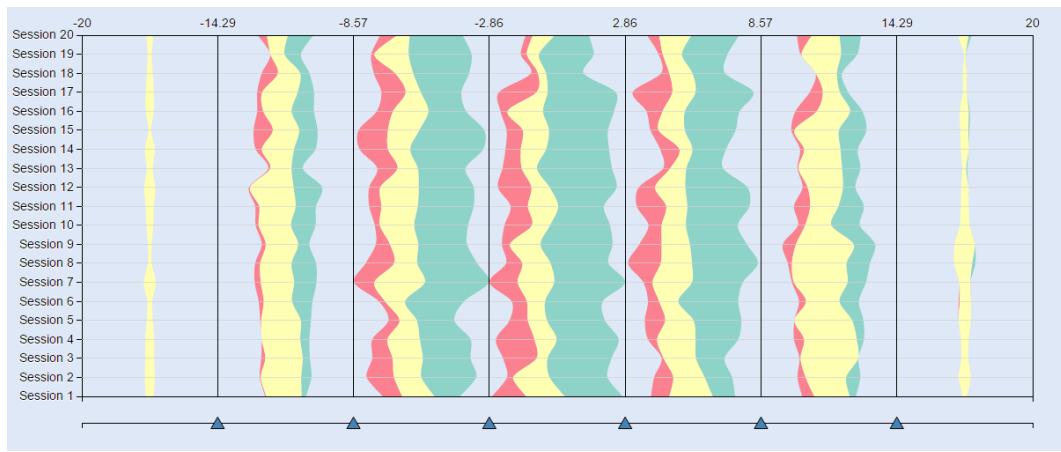


Figure A.5: Summary Visualization by x-range

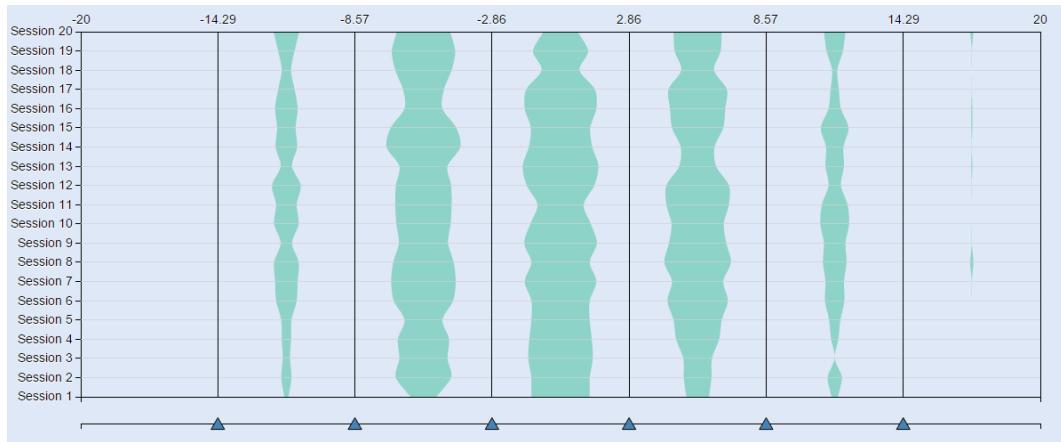


Figure A.6: Summary Visualization by x-range, filtered for positive events

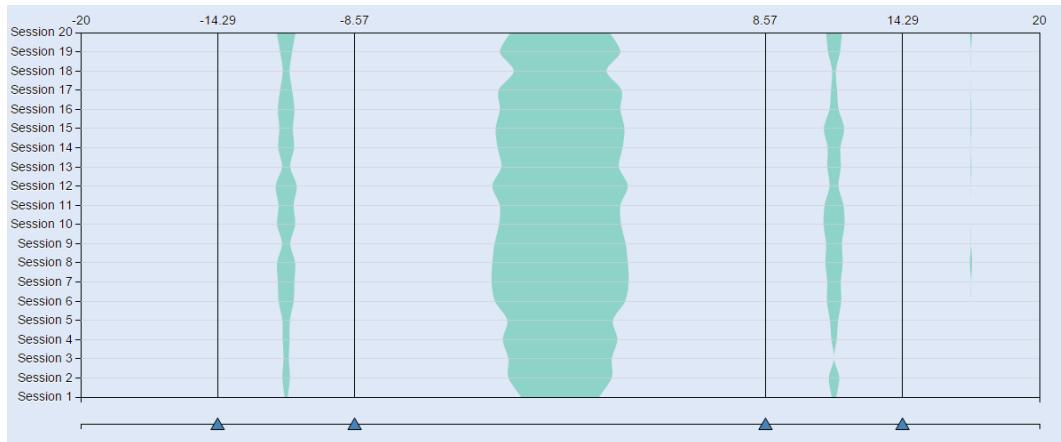


Figure A.7: Summary Visualization by x-range, filtered for positive events and clustered

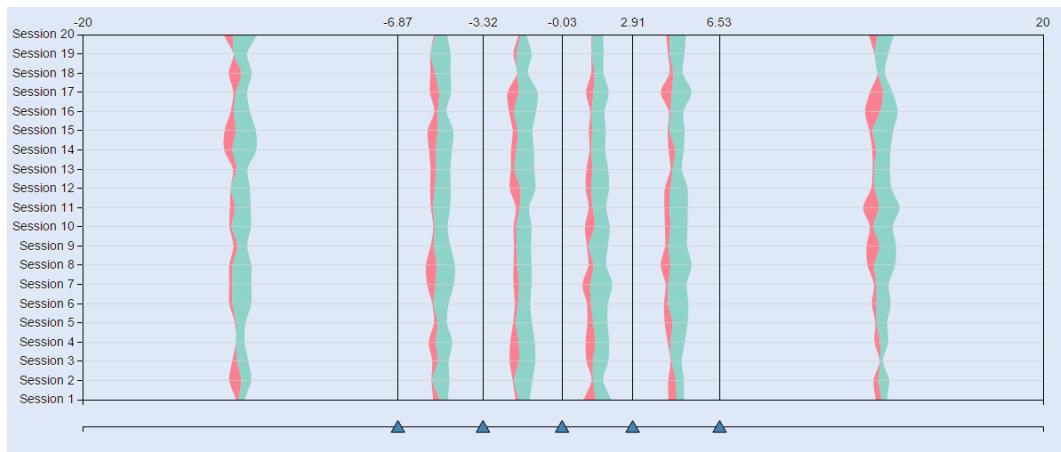


Figure A.8: Summary Visualization by number of events, filtered for positive and negative events

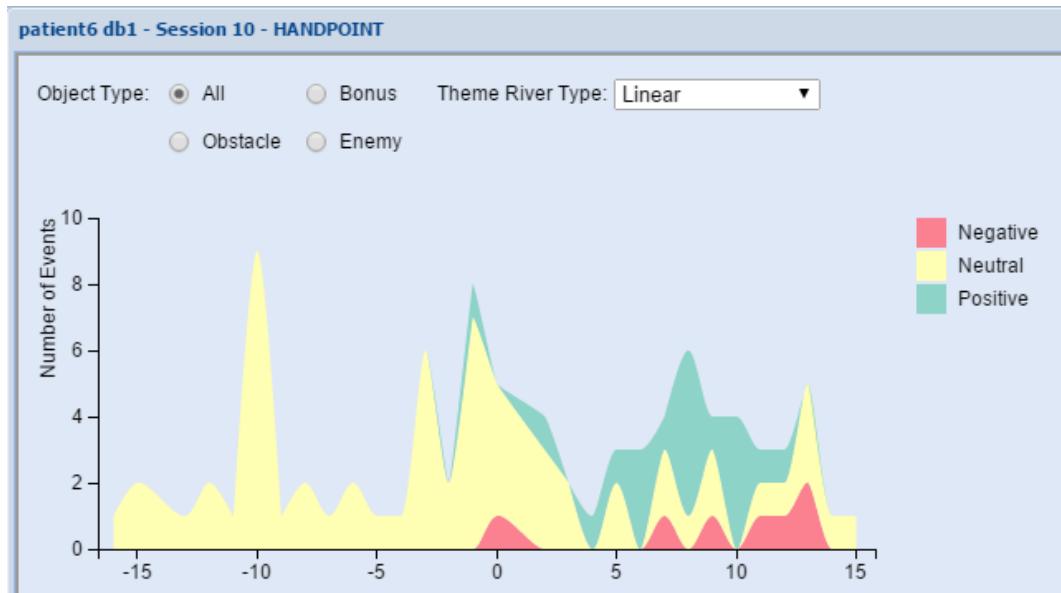


Figure A.9: Stacked Graph of Session 10

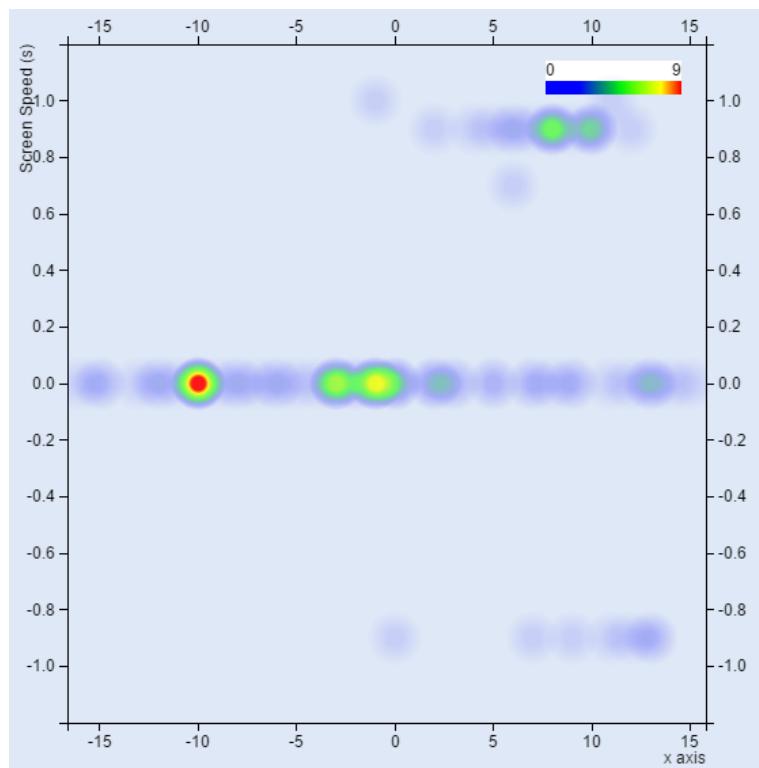


Figure A.10: Heatmap of Session 10

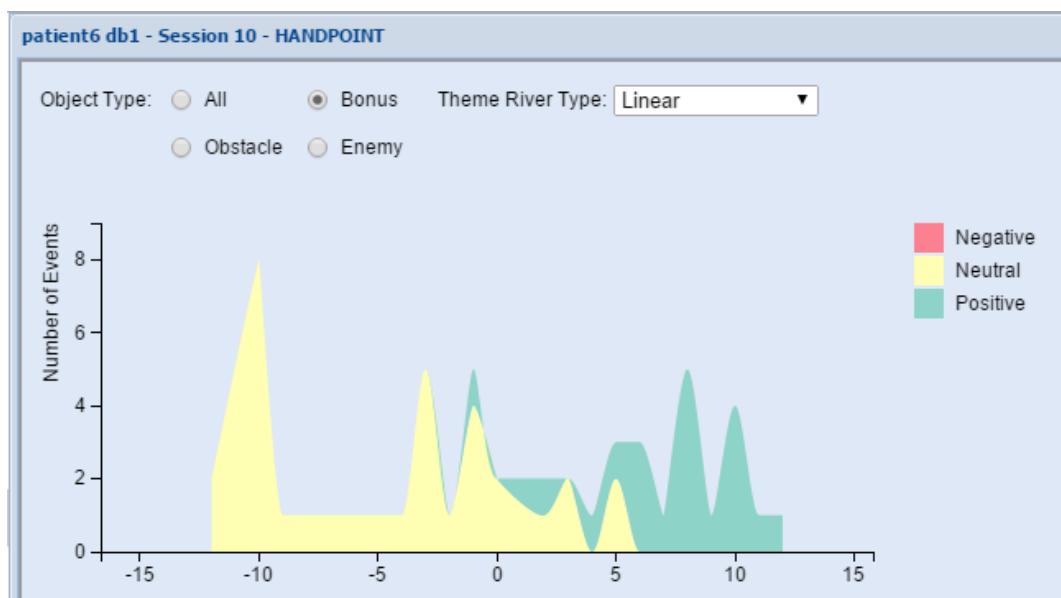


Figure A.11: Stacked Graph of Session 10, filtered by bonus

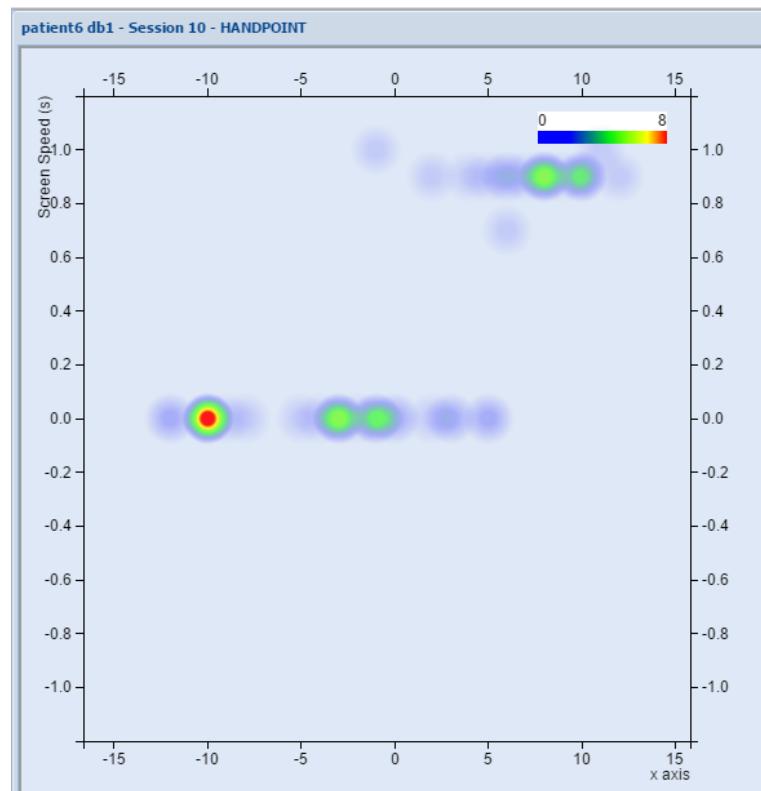


Figure A.12: Heatmap of Session 10, filtered by bonus

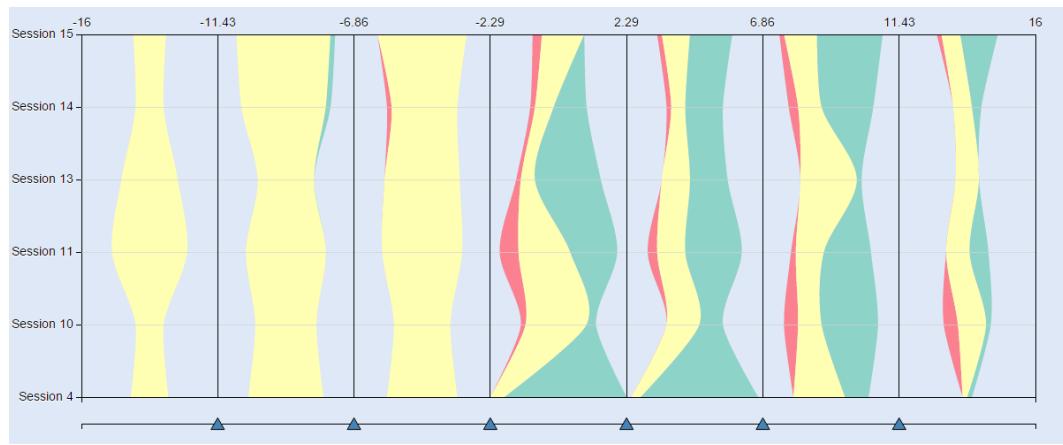


Figure A.13: Summary visualization of Patient 6

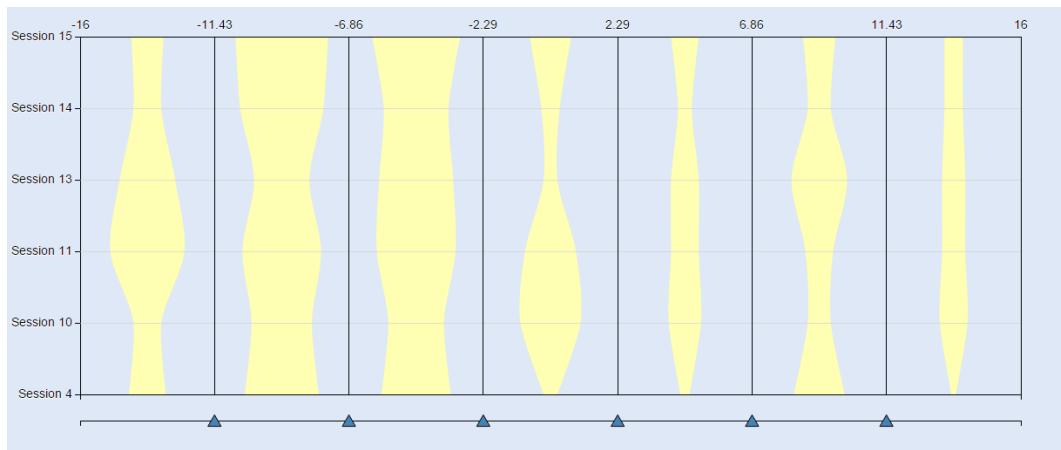


Figure A.14: Summary visualization of Patient 6, filtered by neutral events

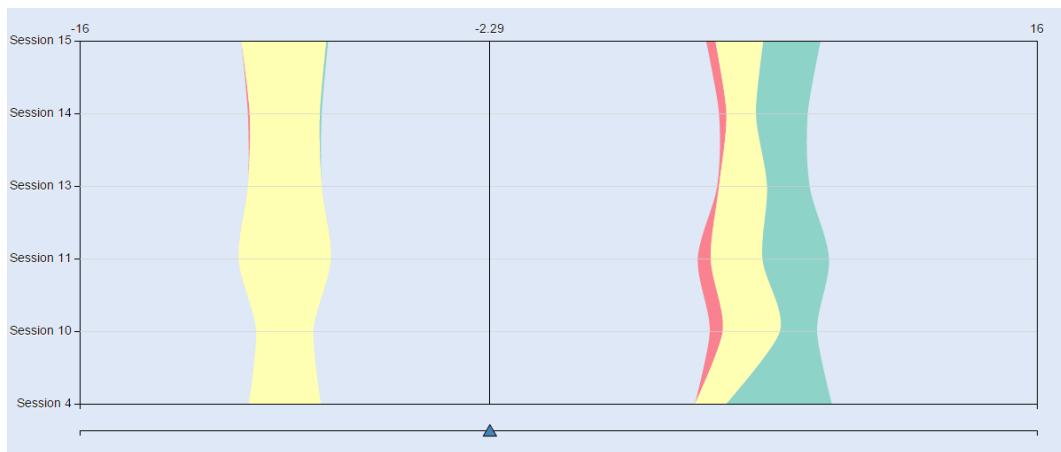


Figure A.15: Summary visualization of Patient 6, clustered

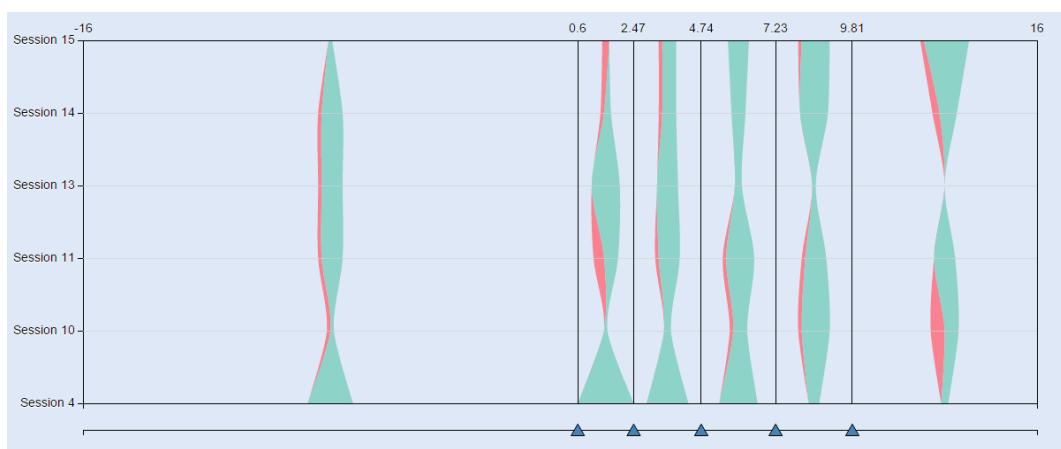


Figure A.16: Summary visualization of Patient 6 with sections divided by number of events, filtered by positive and negative events

Bibliography

- [1] Wolfgang Aigner, Silvia Miksch, Heidrun Schumann, and Christian Tominski. *Visualization of Time-Oriented Data*. Human-Computer Interaction Series. Springer, 2011. (Cited on page 11.)
- [2] Gennady L. Andrienko, Natalia V. Andrienko, Peter Bak, Daniel A. Keim, and Stefan Wrobel. *Visual Analytics of Movement*. Springer, 2013. (Cited on pages 13 and 14.)
- [3] Natalia V. Andrienko and Gennady L. Andrienko. Spatial generalization and aggregation of massive movement data. *IEEE Trans. Vis. Comput. Graph.*, 17(2):205–219, 2011. (Cited on pages 11 and 14.)
- [4] Jürgen Bernard, Nils Wilhelm, Björn Krüger, Thorsten May, Tobias Schreck, and Jörn Kohlhammer. Motionexplorer: Exploratory search in human motion capture data based on hierarchical aggregation. *IEEE Transactions on Visualization and Computer Graphics (Proc. VAST)*, December 2013. (Cited on pages 13, 15 and 16.)
- [5] Michael Bostock, Vadim Ogievetsky, and Jeffrey Heer. D3 data-driven documents. *IEEE Transactions on Visualization and Computer Graphics*, 17(12):2301–2309, December 2011. (Cited on page 18.)
- [6] V. Brezinka. Treasure hunt - a serious game to support psychotherapeutic treatment of children. *Studies in Health Technology and Informatics*, 136:71–76, 2008. (Cited on page 1.)
- [7] Lee Byron and Martin Wattenberg. Stacked graphs – geometry & aesthetics. *IEEE Transactions on Visualization and Computer Graphics*, 14(6):1245–1252, November 2008. (Cited on page 24.)
- [8] Jiri Chmelik and Jiri Sochor. Body motion visualization in virtual environment. In *Proceedings of the 30TH CONFERENCE ON GEOMETRY AND GRAPHICS*, pages 119–124, Prague, 2010. MATFYZPRESS. (Cited on page 15.)
- [9] Ines Di Loreto, Benoit Lange, Antoine Seilles, William Dyce, and Sébastien Andary. Game design for all: The example of hammer and planks. *Serious Games Development and Applications*, 8101:70–75, 2013. (Cited on pages 1 and 19.)
- [10] Peter Gatalsky, Natalia Andrienko, and Gennady Andrienko. Interactive analysis of event data using space-time cube. In *Proceedings of the Information Visualisation, Eighth International Conference*, IV ’04, pages 145–152, Washington, DC, USA, 2004. IEEE Computer Society. (Cited on page 11.)
- [11] D.M Gavrila. The visual analysis of human movement. *Comput. Vis. Image Underst.*, 73(1):82–98, January 1999. (Cited on page 15.)
- [12] D. Green and P. Wilson. Use of virtual reality in rehabilitation of movement in children with hemiplegia - a multiple case study evaluation. *Disability and Rehabilitation*, 34:593–604, 2012. (Cited on pages 1 and 9.)

- [13] Susan Havre, Beth Hetzler, and Lucy Nowell. Themeriver: Visualizing theme changes over time. In *Proceedings of the IEEE Symposium on Information Visualization 2000*, INFOVIS '00, pages 115–, Washington, DC, USA, 2000. IEEE Computer Society. (Cited on pages 11 and 24.)
- [14] Yaya Heryadi, M. Ivan Fanany, and A.M. Arymurthy. Grammar of dance gesture from bali traditional dance. *International Journal of Computer Science Issues*, 9:144–149, 2012. (Cited on page 15.)
- [15] Oded Maimon and Lior Rokach. *Data Mining and Knowledge Discovery Handbook*. Springer-Verlag New York, Inc., Secaucus, NJ, USA, 2005. (Cited on page 21.)
- [16] Tamara Munzner. A nested model for visualization design and validation. *IEEE Transactions on Visualization and Computer Graphics*, 15(6):921–928, November 2009. (Cited on page 2.)
- [17] Atsuyuki Okabe, Barry Boots, Kokichi Sugihara, and Sung Nok Chiu. *Spatial Tesselations: Concepts and Applications of Voronoi Diagrams*. Series in Probability and Statistics. John Wiley and Sons, Inc., 2nd ed. edition, 2000. (Cited on page 14.)
- [18] O. Patsadu, C. Nukoolkit, and B. Watanapa. Human gesture recognition using kinect camera. In *Computer Science and Software Engineering (JCSSE), 2012 International Joint Conference on*, pages 28–32, May 2012. (Cited on page 15.)
- [19] Abdur Rahman. Multisensor serious game-based therapy environment for hemiplegic patients. *International Journal of Distributed Sensor Networks*, 2015:12, 2015. (Cited on pages vii, 1, 5, 9 and 10.)
- [20] Md.Abdur Rahman. Multimedia environment toward analyzing and visualizing live kinematic data for children with hemiplegia. *Multimedia Tools and Applications*, 74(15):5463–5487, 2015. (Cited on pages vii, 10 and 11.)
- [21] Michalis Raptis, Darko Kirovski, and Hugues Hoppe. Real-time classification of dance gestures from skeleton animation. In *Proceedings of the 2011 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, SCA '11, pages 147–156, New York, NY, USA, 2011. ACM. (Cited on page 15.)
- [22] Yuko Tashiro and Tsuyoshi Saitoh. A study on motion visualization system using motion capture data. In *ICAT*, pages 314–315. IEEE Computer Society, 2007. (Cited on page 15.)
- [23] Christian Tominski, Petra Schulze-Wollgast, and Heidrun Schumann. 3d information visualization for time dependent data on maps. In *Proceedings of the Ninth International Conference on Information Visualisation*, IV '05, pages 175–181, Washington, DC, USA, 2005. IEEE Computer Society. (Cited on page 11.)
- [24] Ulanbek D. Turdukulov, Menno-Jan Kraak, and Connie A. Blok. Visual analytics: Designing a visual environment for exploration of time series of remote sensing data: In search for convective clouds. *Comput. Graph.*, 31(3):370–379, June 2007. (Cited on page 11.)

