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Master Thesis

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Visual Analytics on Human Body Movement Data Applied on Healthcare

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

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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 :-)

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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[17, 6, 11]. 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)[8]. A person with hemiplegic is paralized on one side of the body[1]. 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[8].

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

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

Figure 1.1: Hammer and Planks Screenshot

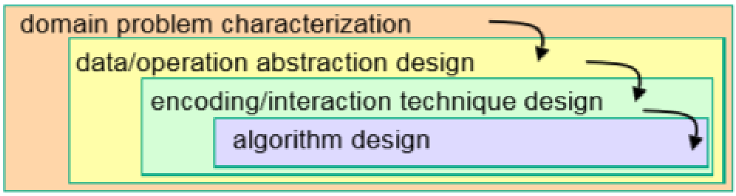

Figure 1.2: Munzner's Visualization Design Model with four nested layers

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 [14]. 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 [17]. 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:

(Q_1) For a given session, to which direction (right/left) the player moved more?

(Q_2) 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?

(Q_3) 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?

(Q_4) For a given patient, has he/she has improved in the game overtime?

(Q_5) For a given patient, has he/she has 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 event type 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 event type 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, [17] presents a rehabilitation framework for hemiplegic patients which combines the use of Kinect and LEAP[1] 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 [11], a virtual reality rehabilitation system for children with hemiplegia was developed using TUI[2]. 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 [17], this system doesn't provide an interface in which therapist can analyse the gameplay.

[1] https://www.leapmotion.com/product/desktop

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

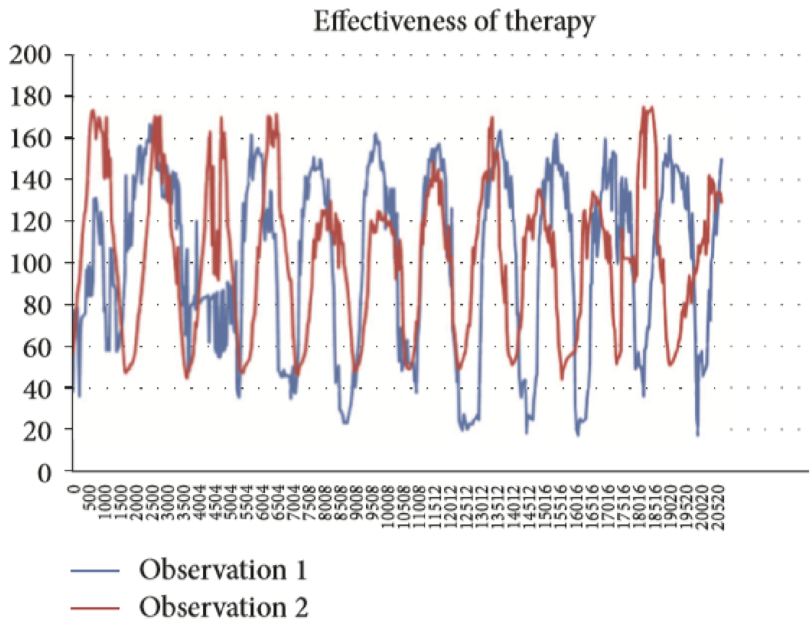

Figure 3.1: Visualization used in [17] depicting the degree of forearm movement overtime

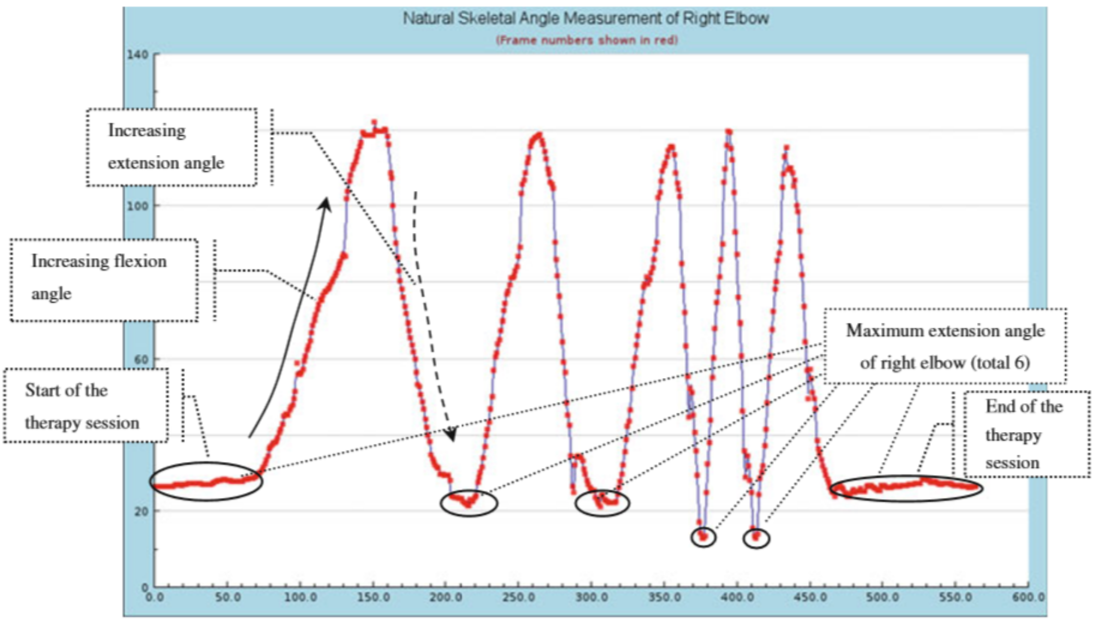

Figure 3.2: Visualization used in [18] depicting the speed of movement (m/s) of forearm overtime

Similar to Hammer and Planks, [18] introduced a framework which uses Kinect attached to Second Life[3] 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 [22], human health [21] and earthquake events [9] 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 [12], Theme River is used to visualize thematic changes over time of document collection. Each theme is represented as different colors

[3] http://secondlife.com/

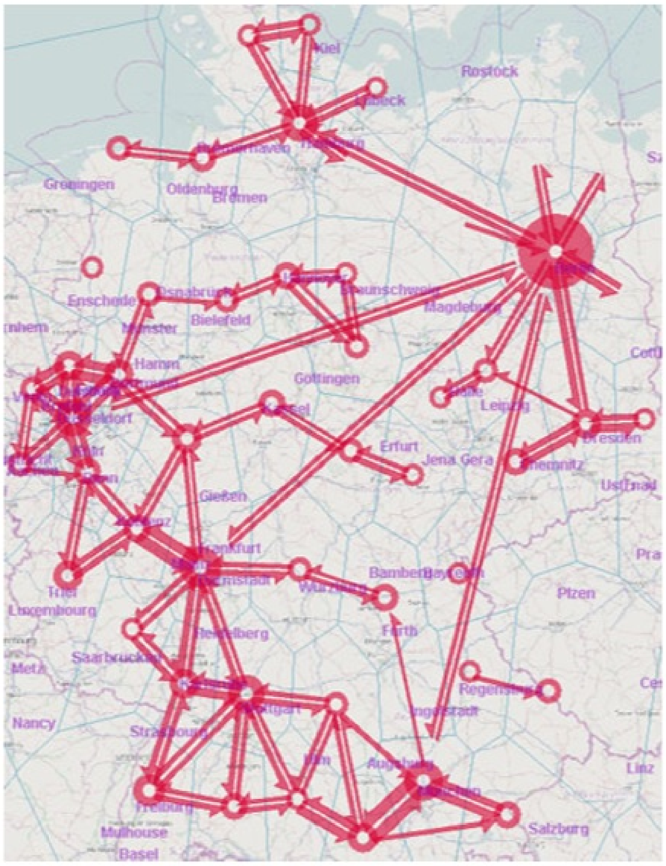

Figure 3.3: Flow Map

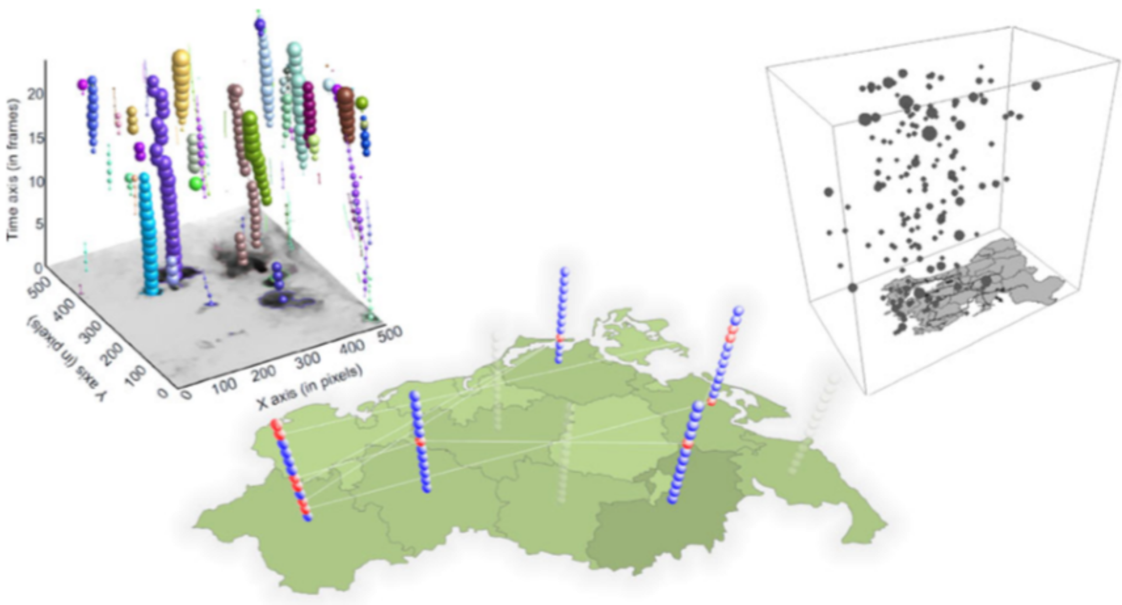

Figure 3.4: Spatio-Temporal Event Visualization

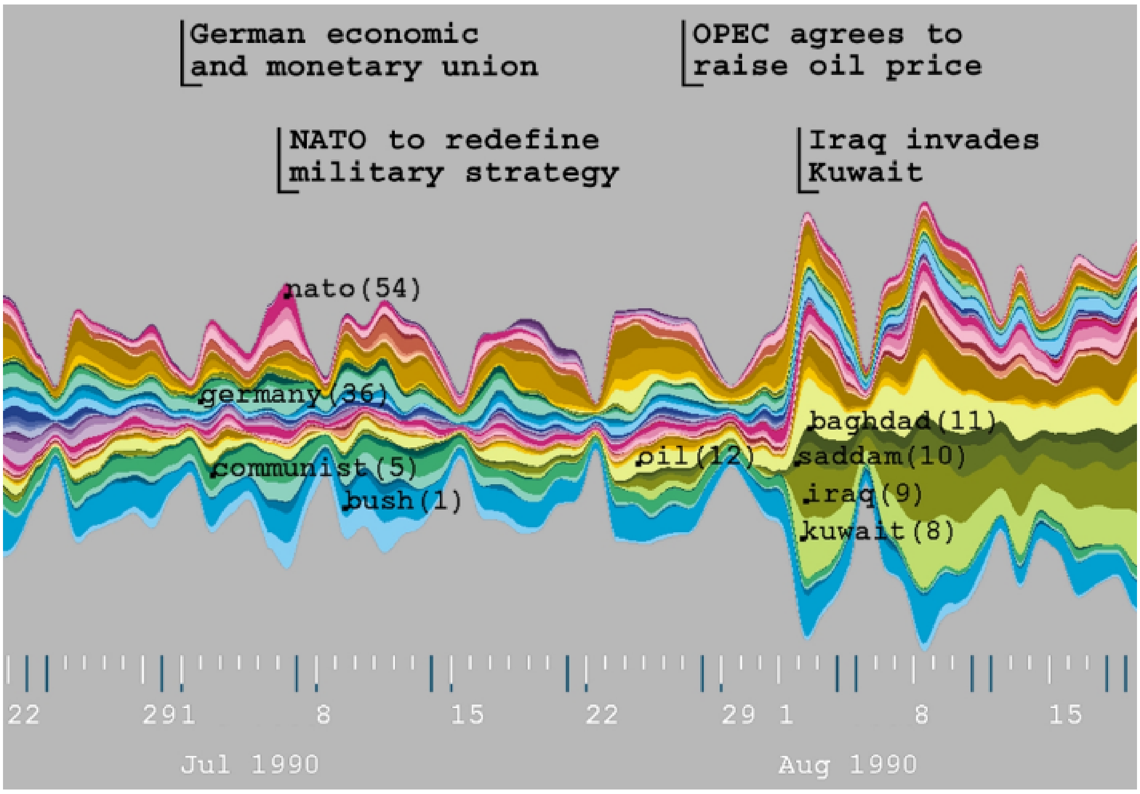

Figure 3.5: Theme River

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

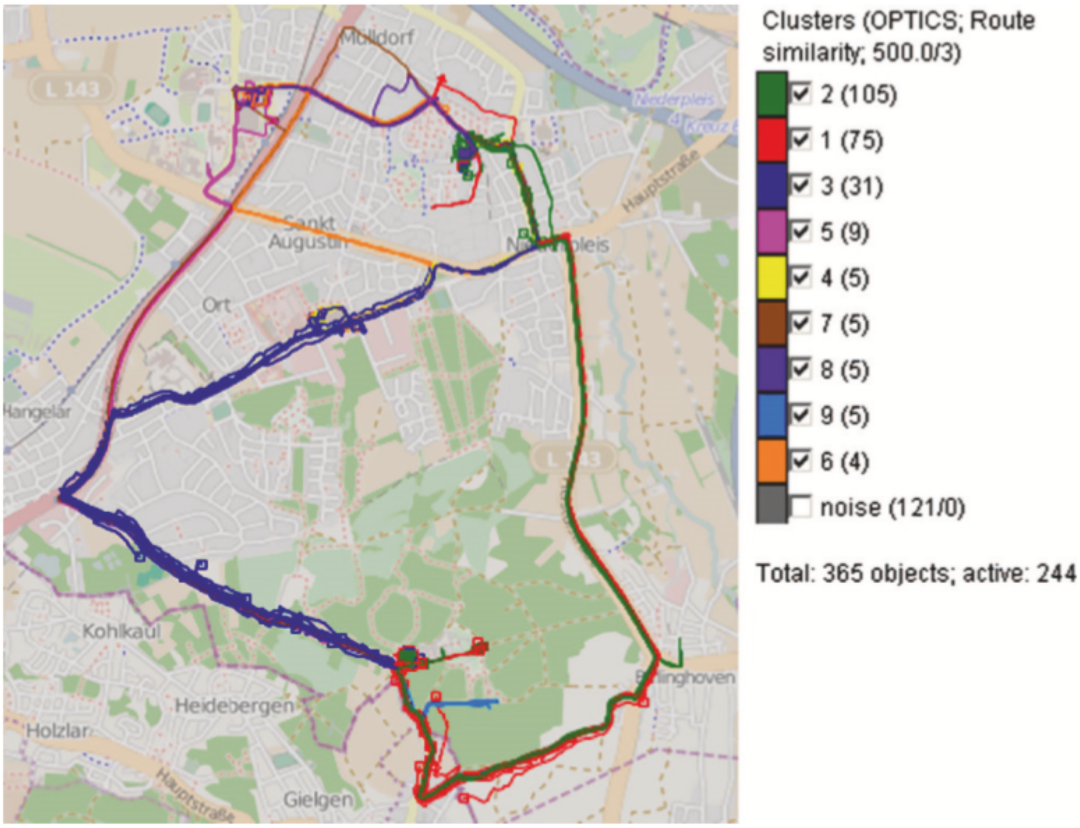

Figure 3.6: Theme River

body movement focusing on visualization for skeleton animation[4] 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 [15]) during certain time period. The number

[4]https://en.wikipedia.org/wiki/Skeletal_animation)

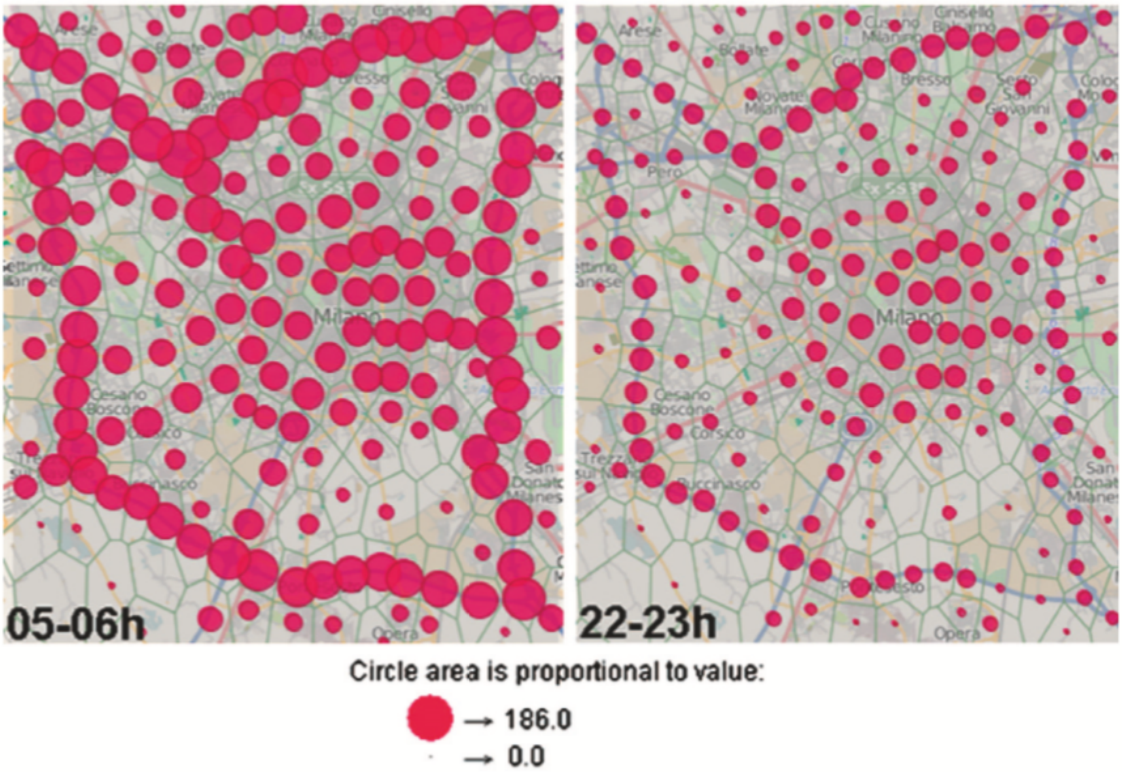

Figure 3.7: Theme River

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[13, 19], sports[4], healthcare[16], etc. There are numerous research has been done concerning human movement analysis as discussed in [10] 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.

[7] 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 [7] 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 [20]. In this approach, movement data collected from motion capture system with 11 sensors attached

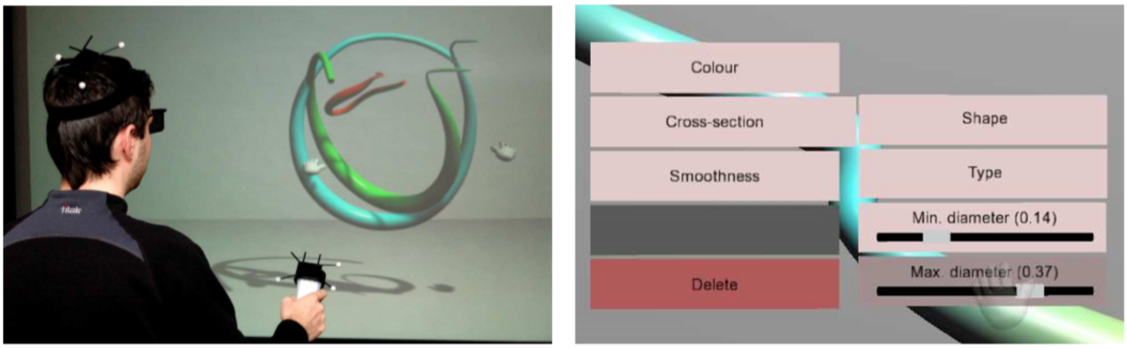

Figure 3.8: Motion Trail

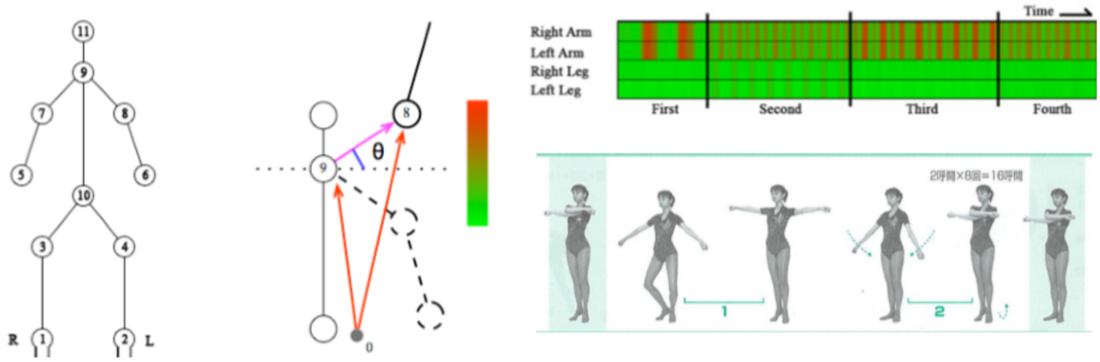

Figure 3.9: Motion Trail

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

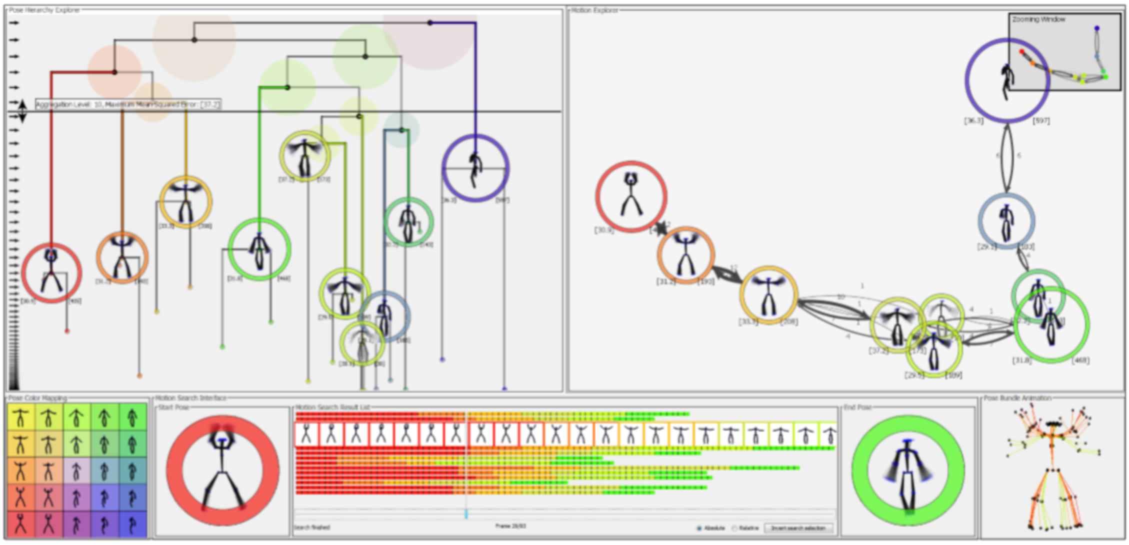

Figure 3.10: MotionExplorer interface

hierarchy is shown as a dendogram 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

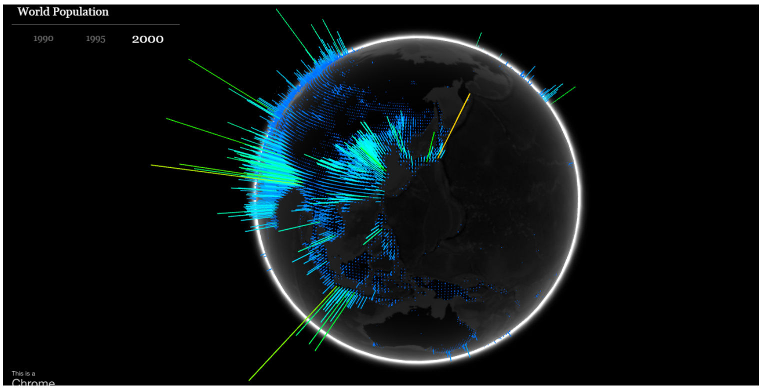

Figure 3.12: 3D visualization of world population developed in Three.js

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 user[6].

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 complexity[7]. The features[8] 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[8]. 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 catched

(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:

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

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. 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(υ_{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.

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

4.2 Clustering Algorithm

clustering model is also in this part to see what common evolution of section of the game

Chapter 5

Visual Mappings And Interactive Functionality

define the slice(triplets) here. choices to make the visualization, why stream graph, why there is no second slider, all the interface. when create your structure and visual mapping, write: this part for this requirement. we can put several requirement for one thing. the goal is to show to the reviewer that each time you make a choice in your visual design, it is to answer certain requirement. To show that nothing is random and everything is made to respond to the requirement.

5.1 Theme River

5.2 Heat Map

5.3 Summary Theme River

Chapter 6

Case Studies

write a kind of stories. Looking at this visualization, I see this and that. This correspond to this task and this task. find at least one example for all the task we've defined before. We can say: here, there is a difference between people with pathology and without pathology. for ex: the movement are only in the middle for the people with pathology, while for normal people, there are movement on the side as well. for ex: there are a lot of green in this part. there are less event at the beginning, when there are more event, then there are more red area.

6.1 Normal Player

6.2 Patient

Chapter 7

Conclusion

Appendix A

Appendix Example

A.1 Appendix Example section

And I cite myself to show by bibtex style file (two authors).

This for other bibtex stye file : only one author [8] and many authors [8].

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] 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.)

[8] Ines Di Loreto, Benoit Lange, Antoine Seilles, William Dyce, and Sebastien Andary. Game design for all: The example of hammer and planks. *Serious Games Development and Applications*, 8101:70–75, 2013. (Cited on pages 1, 19 and 27.)

[9] 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.)

[10] D.M Gavrila. The visual analysis of human movement. *Comput. Vis. Image Underst.*, 73(1):82–98, January 1999. (Cited on page 15.)

[11] 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.)

[12] Susan Havre, Beth Hetzler, and Lucy Nowell. Themeriver: Visualizing theme changes over time. In *Proceedings of the IEEE Symposium on Information Vizualization 2000*,

INFOVIS '00, pages 115–, Washington, DC, USA, 2000. IEEE Computer Society. (Cited on page 11.)

[13] 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.)

[14] 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.)

[15] Atsuyuki Okabe, Barry Boots, Kokichi Sugihara, and Sung Nok Chiu. *Spatial Tessellations: Concepts and Applications of Voronoi Diagrams.* Series in Probability and Statistics. John Wiley and Sons, Inc., 2nd ed. edition, 2000. (Cited on page 14.)

[16] 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.)

[17] 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.)

[18] 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.)

[19] 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.)

[20] 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.)

[21] 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.)

[22] 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.)