# Decision Support and Business Intelligence

***Information Technologies for Business Intelligence***

# Master Thesis

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# Visual Analytics on Human Body Movement Data Applied on Healthcare

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[9, 3, 6]. 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)[4]. 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[4].

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

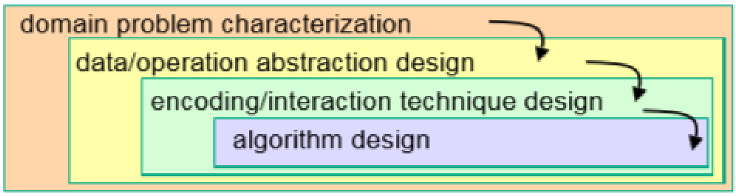


Figure 1.2: Munzner's Visualization Design Model with four nested layers

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 [8]. 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 [9]. By the end of the session, the therapist will

(a) BodyTilt (b) HandPoint

Figure 2.1: Hammer and Planks movement type

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, [9] 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 [6], 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 [9], this system doesn't provide an interface in which therapist can analyse the gameplay.

Similar to Hammer and Planks, [10] introduced a framework which uses Kinect attached to Second Life[3] serious game environment. The mission of the game is to follow

[1] https://www.leapmotion.com/product/desktop
[2] https://en.wikipedia.org/wiki/Tangible_user_interface
[3] http://secondlife.com/

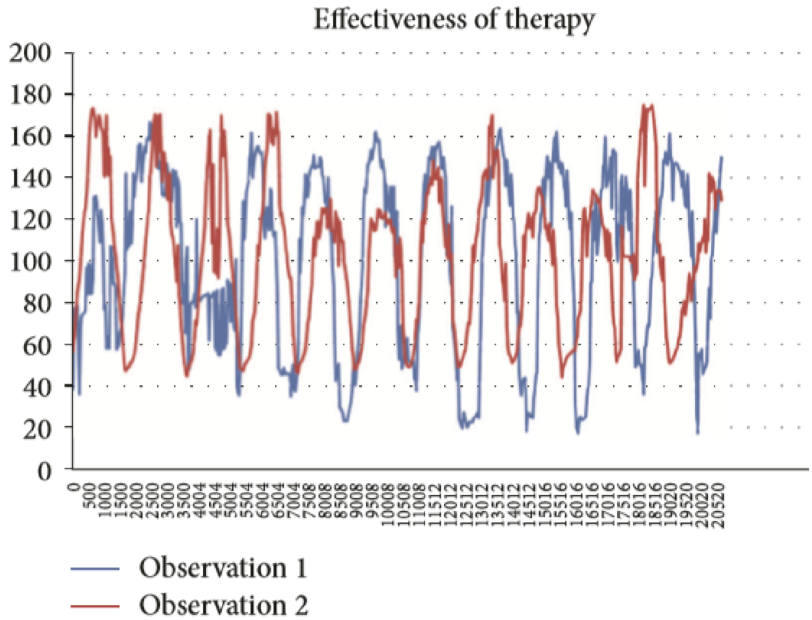


Figure 3.1: Visualization used in [9] depicting the degree of forearm movement overtime

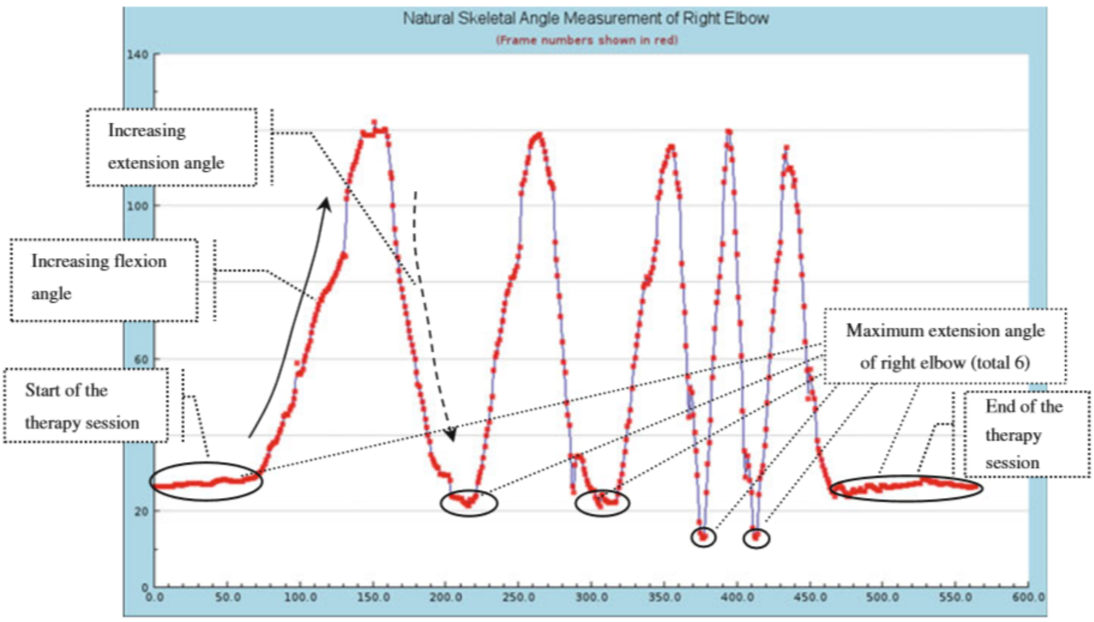


Figure 3.2: Visualization used in [10] depicting the speed of movement (m/s) of forearm overtime

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 [2]. 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 [12], human health [11] and earthquake events [5] 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 [7], Theme River is used to visualize thematic 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

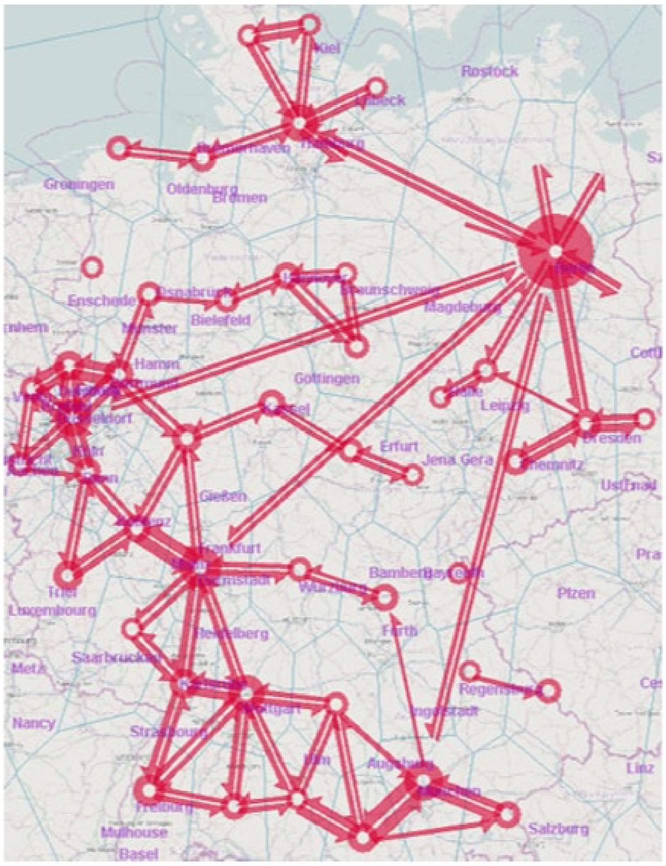


Figure 3.3: Flow Map

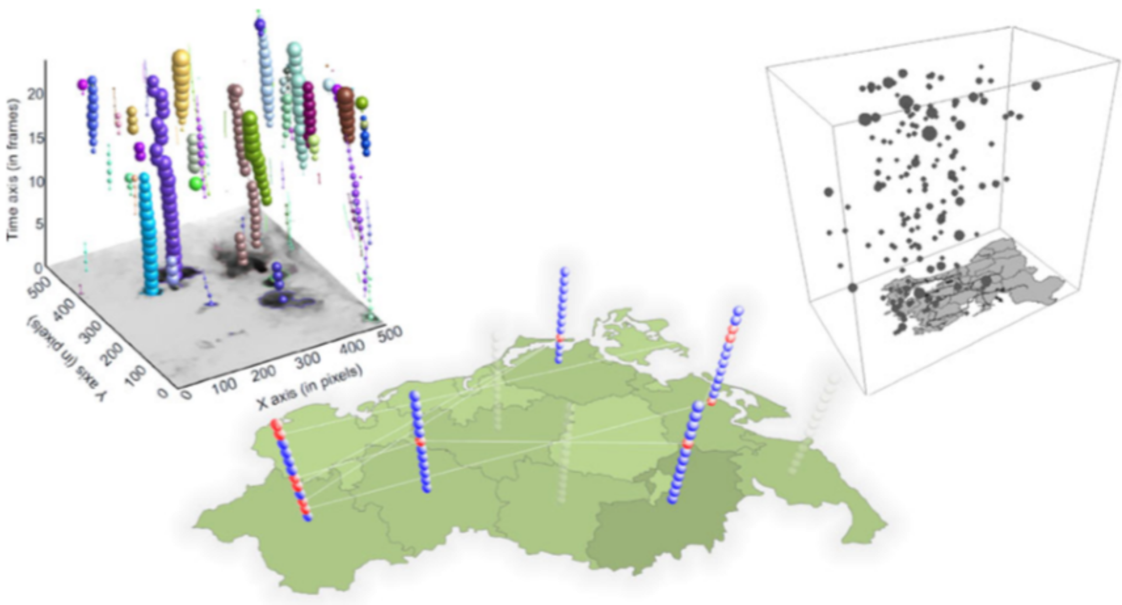


Figure 3.4: Spatio-Temporal Event Visualization

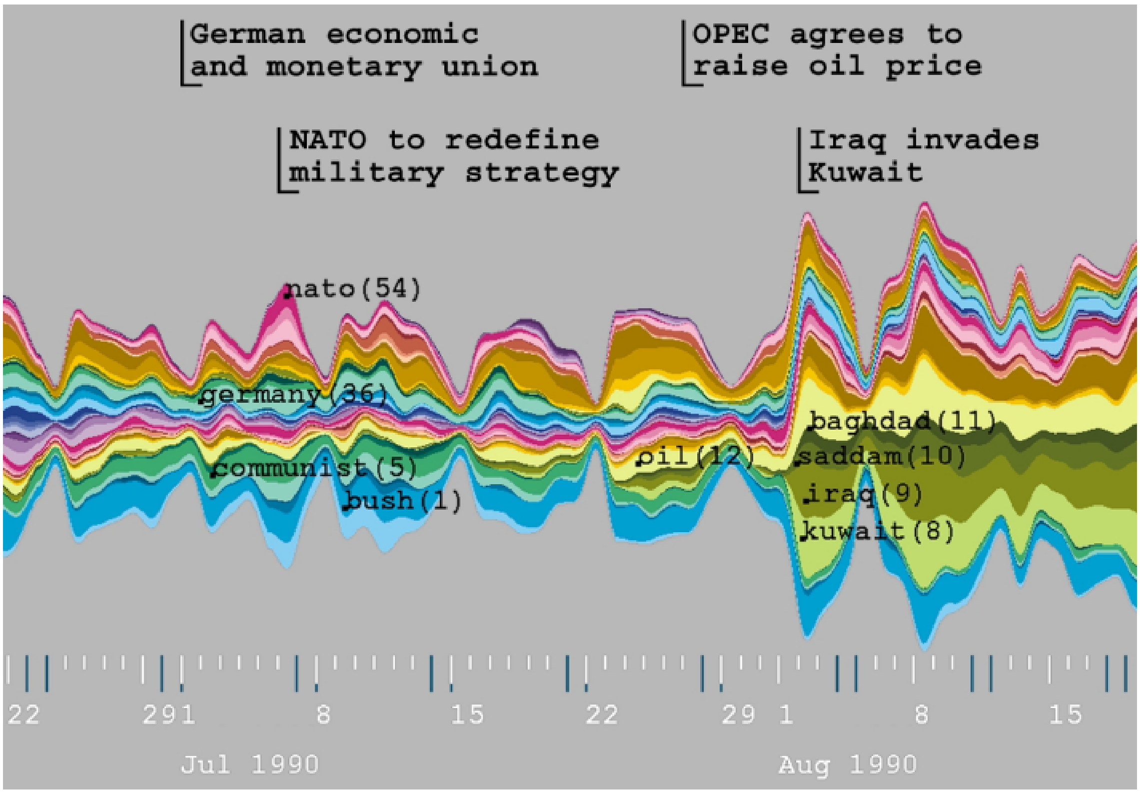


Figure 3.5: Theme River

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

– Andrienko's paper and book: related to movement data in general – MotionExplorer: related to body movement data

## 3.4 Data Visualization Tool

### 3.4.1 D3.js

general explanation of d3js and some example of how it is used to visualize time series and movement data.

### 3.4.2 Three.js

general explanation of three.js and some example.

Chapter 4

# Data Abstraction

The data we explore... Our targeted data type is .. collected over... Typically, they containe... Discuss about the input (log file) of the application.

## 4.1 Game Events Structure

take raw data and then define high level structure we use to deal with enemies, obstacles, obstacles. For each event, we assign a value () => to characterize the event

## 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 [4] and many authors [4].

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