Visual Analytics on Human Body Movement Data

Applied on Healthcare

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Outline

Motivation

Figure: Kinect

Figure: Wii Remote

Figure: Wii Balance Board

Figure: Play Station Move

Motion Sensing input devices enable players to control and interact with the game console through body movement.

Motivation

Figure: Hammer and Planks Interface

- Hammer and Planks is a serious game designed to train the equilibrium of patient with balance disorders (ie. Hemiplegic people).
- Players are required to move their body parts to the right, left, backward, and forward as part of the rehabilitation
- Game missions: collect bonuses, kill enemies, avoid obstacles

Motivation

With current visualization, the information
Available:

- Average degree of body movement over x axis
- Average degree of body movement over y axis

Not Available:

- How often the player move to right or left?
- To which type of events (collecting bonuses, killing enemies) the movement is related?
- Evolution of player's movement

Methodology

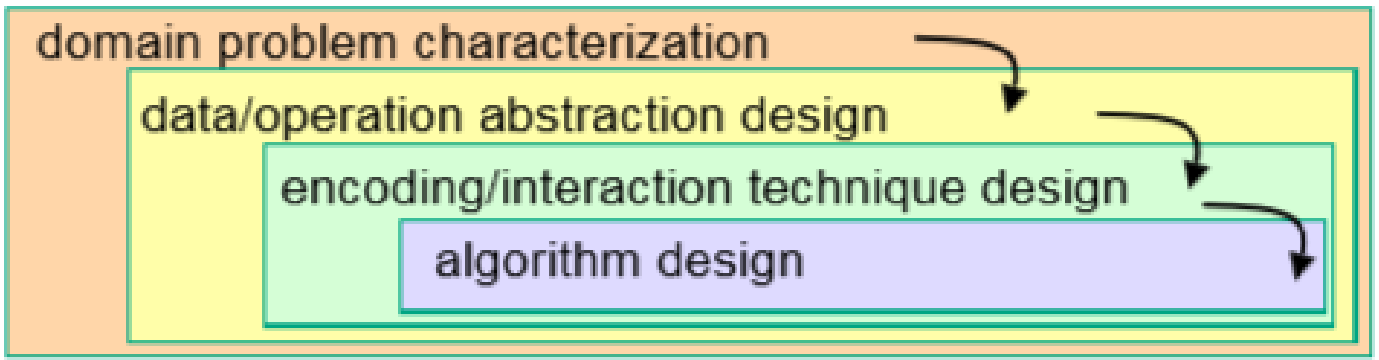

Figure: Munzner's Visualization Design Model

- What kind of information needed by health professionals from the visualization (List of Tasks)
- Define data structure to support the tasks
- Define visualization and interaction technique

Hammer and Planks Game Dynamic

Figure: BodyTilt

Figure: HandPoint

- Healthcare professional can adjust game difficulty by setting the number of objects, area where objects can appear, activity duration and repetition
- Movement Setting: BodyTilt, HandPoint, ShoulderCGE
- Game Direction: Vertical, Horizontal, Both

Target User Question

(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 has improved in the game overtime?
(Q5) For a given patient, has he/she has improved in a certain area overtime?

Visualization Requirements

Tasks related to a session of a particular player:
(T1.1) visualize and be able to compare the number of events within the same or among different event type at a given x area (Q1)(Q2).
(T1.2) visualize and be able to compare the number of events and its screen speed of the same or among different event type at a given x area (Q1)(Q2)(Q3).
(T1.3) select and visualize the number of events for a certain object at a given x area (Q1)(Q2).
(T1.4) select and visualize the number of events and its screen speed for a certain object at a given x area (Q1)(Q2)(Q3).

Visualization Requirements

Tasks related to the summary of all sessions of a player:
(T2.1) visualize, navigate and be able to compare the evolution of number of events throughout all sessions within a certain x area.(Q4)(Q5).
(T2.2) select and visualize the number of events of a certain event type in a certain x area throughout all sessions (Q4)(Q5).
(T2.3) visualize, navigate and be able to compare the distribution of a certain number of events over x area among all sessions(Q4)(Q5).
(T2.4) select and visualize the distribution of certain number of events over x area for a certain event type throughout all sessions (Q4)(Q5).
(T2.5) extract and visualize similar pattern of number of events evolution throughout all sessions over a certain x area (Q4)(Q5).

Visualization of Serious Game Result

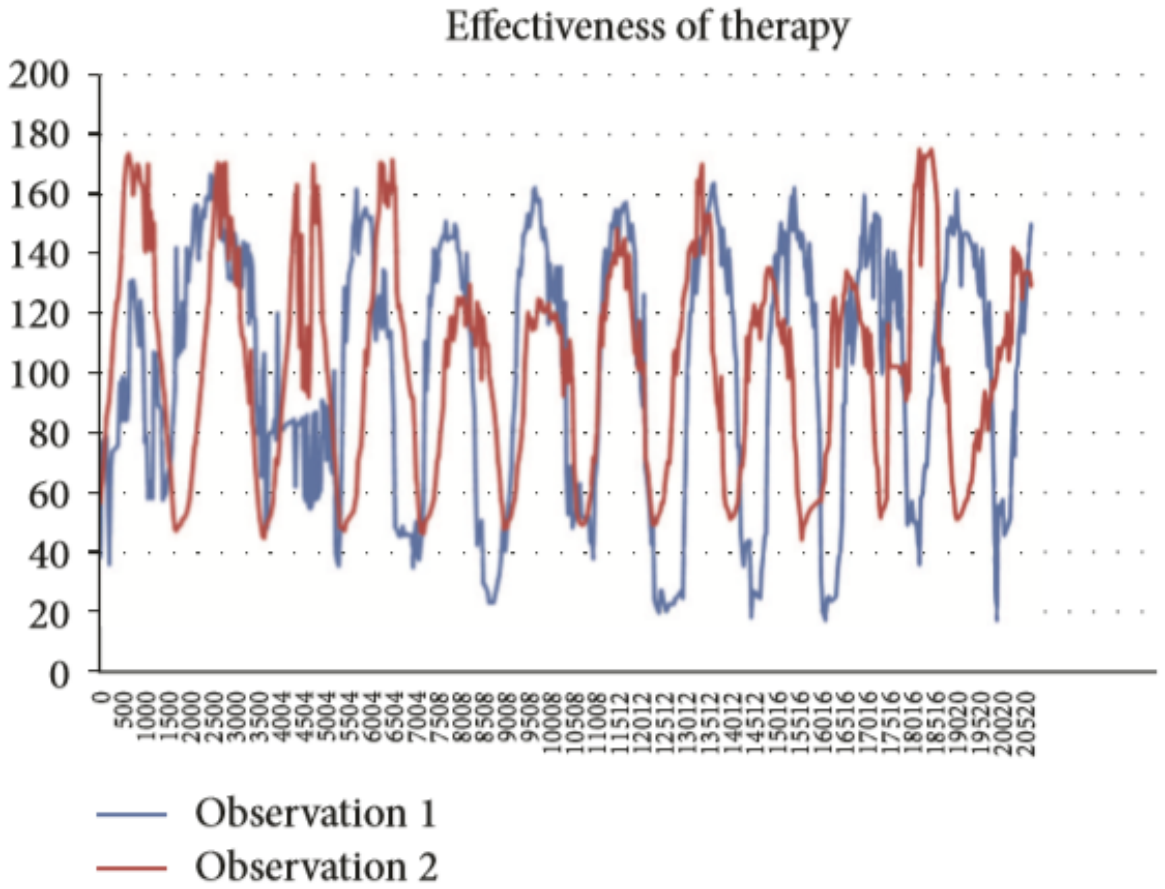

Figure: Line Chart depicting degree of forearm movement over time

Visualization of Time Series Data

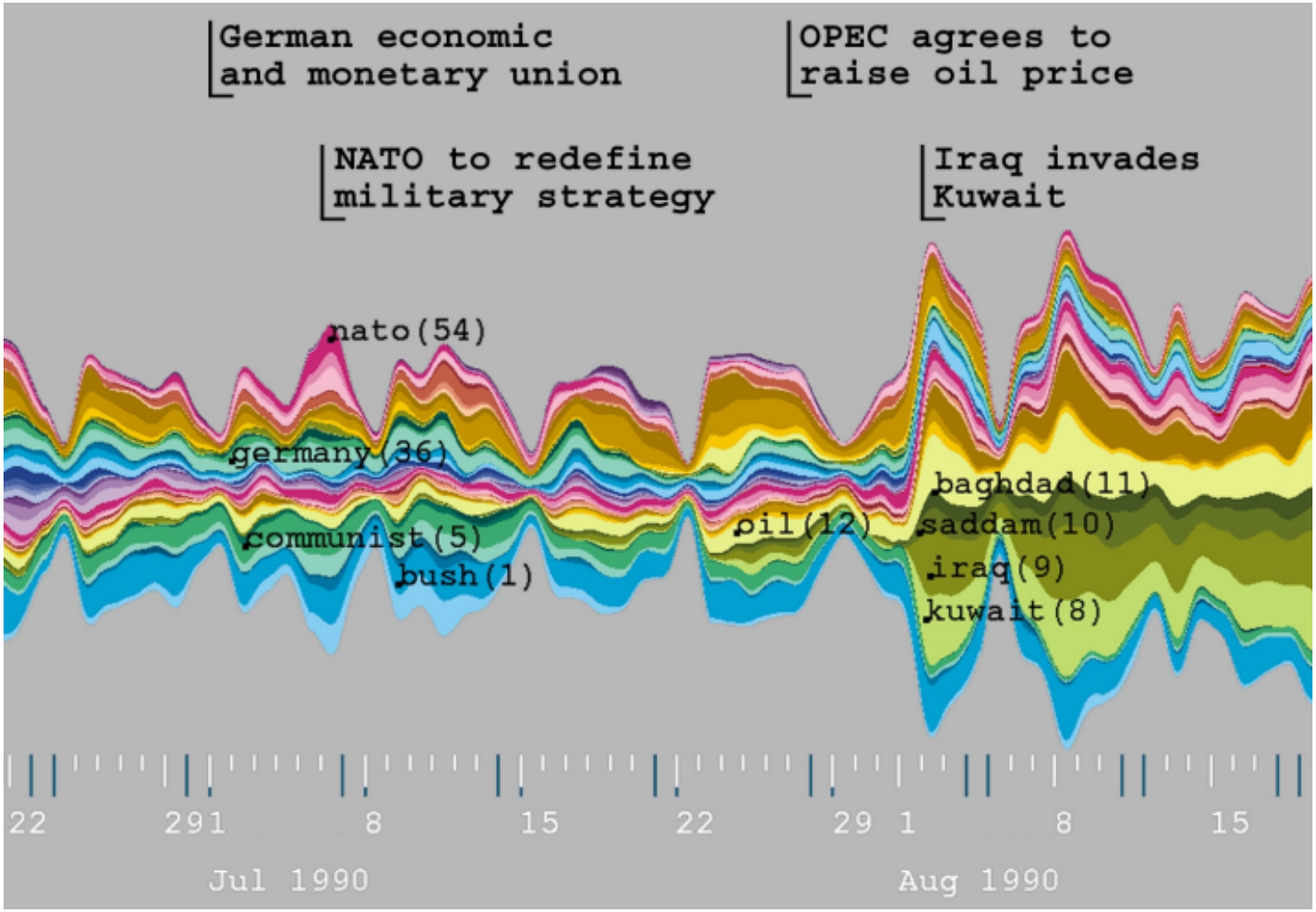

Figure: Theme River

Visualization of Movement Data

Figure: Motion Explorer

Game Events Structure

- Event Category: Positive, Neutral, Negative

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

- Screen Speed: distance between apparition location and event location divided by duration between apparition time and event time

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

Clustering - Distance Calculation

- To see common evolution of different section of x-area, consecutive sections with similar movement distribution are clustered together
- Let S be a gameplay data set of n_{ses} sessions.
- S is an ordered list of sections $s_i, 0 \leq i < n_{sec}$. Each section contains events occurred on an x-axis unit among all sessions.
- A section s_i is a sequence of triplets $s_i[j], 0 \leq j < n_{ses}$. Each triplet represents data set of a certain game session of a particular section s_i.
- The triplet consists of the number of negative, neutral and positive events.
- The profile of each section can be represented by a matrix of n_{ses} x 3 dimensions.

$$s_1 = \begin{bmatrix} 10 & 20 & 6 \\ 20 & 5 & 18 \end{bmatrix} s_2 = \begin{bmatrix} 20 & 40 & 10 \\ 40 & 10 & 30 \end{bmatrix} s_3 = \begin{bmatrix} 10 & 20 & 5 \\ 16 & 4 & 12 \end{bmatrix}$$

Clustering - Distance Calculation

- Similarity between two sections is quantified with distance function (distance=0:similar; distance=1: different)
- Two types of distance:
  - How different both sections in term of event types proportion within each section (s_2 is similar to s_3)
  - How different both sections in term of the evolution of each event type throughout the sessions (s_1 is similar to s_2)

$$s_1 = \begin{bmatrix} 10 & 20 & 6 \\ 20 & 5 & 18 \end{bmatrix} s_2 = \begin{bmatrix} 20 & 40 & 10 \\ 40 & 10 & 30 \end{bmatrix} s_3 = \begin{bmatrix} 10 & 20 & 5 \\ 16 & 4 & 12 \end{bmatrix}$$

- For each pair of consecutive sequences (s_1,s_2) of S, distance is weighted sum of two distance types, represented as $f(s_1, s_2)$ and $g(s_1, s_2)$.

$$d(s_1, s_2) = \alpha f(s_1, s_2) + (1 - \alpha) g(s_1, s_2)$$

Clustering - Distance Calculation

- $f(s_1, s_2)$ is a normalized euclidean distance of two triplets.
- Distance is the average euclidean distance of each triplets pair.

$$f(s_1, s_2) = \frac{\sum_{i=0}^{i<|s_1|} NED(s_1[i], s_2[i])}{|s_1|}$$

- Distance is normalized by dividing it with maximum distance $\sqrt{3}$.

$$NED(s_1[i], s_2[i]) = \frac{\sqrt{\sum_{j\in\{0,1,2\}} (s_1'[i][j] - s_2'[i][j])^2}}{\sqrt{3}}$$

- s_1' and s_2' is normalized value of s_1 and s_2 (divided by max value of each session in each section)

Clustering - Distance Calculation

$$s_1 = \begin{bmatrix} 10 & 20 & 6 \\ 20 & 5 & 18 \end{bmatrix} s_2 = \begin{bmatrix} 20 & 40 & 10 \\ 40 & 10 & 30 \end{bmatrix} s_3 = \begin{bmatrix} 10 & 20 & 5 \\ 16 & 4 & 12 \end{bmatrix}$$

$$s_1' = \begin{bmatrix} \frac{1}{2} & 1 & \frac{6}{20} \\ 1 & \frac{1}{4} & \frac{18}{20} \end{bmatrix} s_2' = \begin{bmatrix} \frac{1}{2} & 1 & \frac{1}{4} \\ 1 & \frac{1}{4} & \frac{3}{4} \end{bmatrix} s_3' = \begin{bmatrix} \frac{1}{2} & 1 & \frac{1}{4} \\ 1 & \frac{1}{4} & \frac{3}{4} \end{bmatrix}$$

Clustering - Distance Calculation

- $g(s_1, s_2)$ is based on a normalized euclidean distance between the same event type j from different section.
- The overall distance of both sections is the average euclidean distance of each event type pair.

$$g(s_1, s_2) = \frac{g_0(s_1, s_2) + g_1(s_1, s_2) + g_2(s_1, s_2)}{3}$$

- For each event type distance, there are three different distance value defined:
  - if there are no events in both event type pairs, the distance is 0
  - if there is at least one event in one section and there are no events in the other section, the distance is 1
  - if both event type pairs has any events then the euclidean distance is calculated

Clustering - Distance Calculation

for $j \in \{0, 1, 2\}$,

$$g_j(s_1, s_2) = \begin{cases} 0 & \text{if } s_k[i][j] = 0 \text{ for each } 0 \leqslant j < |s_k| \text{ and } k \in \{1, 2\} \\ 1 & \text{if } s_k[i][j] = 0 \text{ for each } 0 \leqslant j < |s_k| \text{ and } \exists s_p[i][j] \neq 0, \\ & k, p \in \{1, 2\},\ k \neq p \\ \dfrac{\sqrt{\sum_{i=0}^{|s_1|} (s_1''[i][j] - s_2''[i][j])^2}}{\sqrt{|s_1|}} & \text{otherwise} \end{cases}$$

- s_1'' and s_2'' represent normalized value of s_1 and s_2 (divided by max value of each event type in each section)

Clustering Algorithm

$$s_1 = \begin{bmatrix} 10 & 20 & 6 \\ 20 & 5 & 18 \end{bmatrix} s_2 = \begin{bmatrix} 20 & 40 & 10 \\ 40 & 10 & 30 \end{bmatrix} s_3 = \begin{bmatrix} 10 & 20 & 5 \\ 16 & 4 & 12 \end{bmatrix}$$

$$s_1'' = \begin{bmatrix} \frac{1}{2} & 1 & \frac{1}{3} \\ 1 & \frac{1}{4} & 1 \end{bmatrix} s_2'' = \begin{bmatrix} \frac{1}{2} & 1 & \frac{1}{3} \\ 1 & \frac{1}{4} & 1 \end{bmatrix} s_3'' = \begin{bmatrix} \frac{5}{8} & 1 & \frac{5}{12} \\ 1 & \frac{1}{5} & 1 \end{bmatrix}$$

Clustering Algorithm

1. Divide data set into sections the size of x-axis unit
2. Calculate distance between two consecutive sections
3. Cluster sections with distance below threshold. This results in a new set of sections
4. Recalculate distance and cluster
5. Repeat the process until there is no sections with distance below the threshold

Session Visualization - Stacked Graph (T1.1)

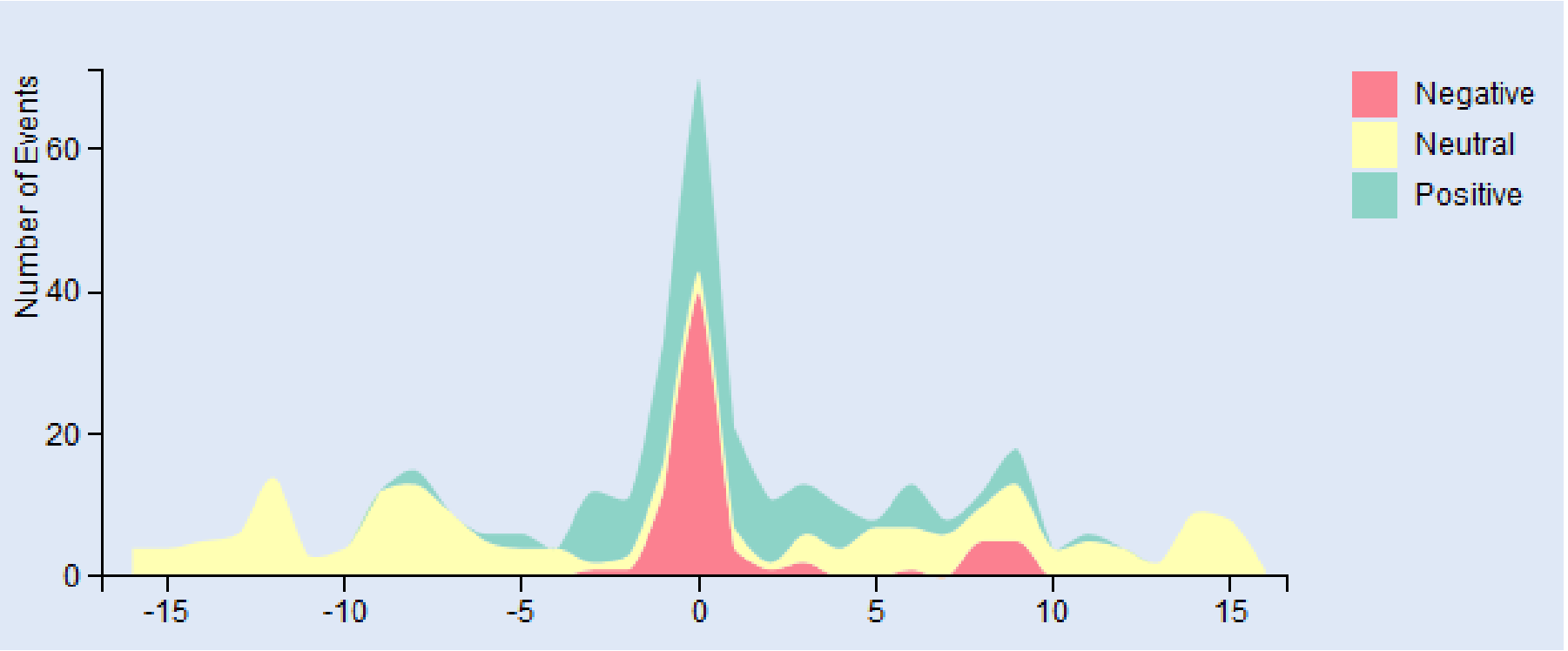

Figure: Stacked Graph depicting number of events over x axis

Session Visualization - Stacked Graph Layout

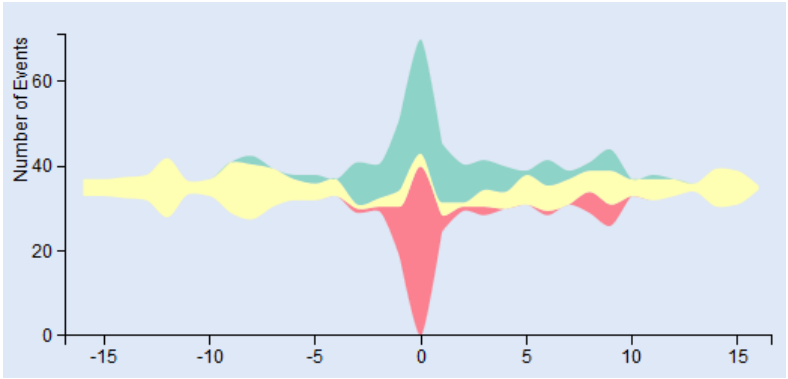

Figure: Silhouette

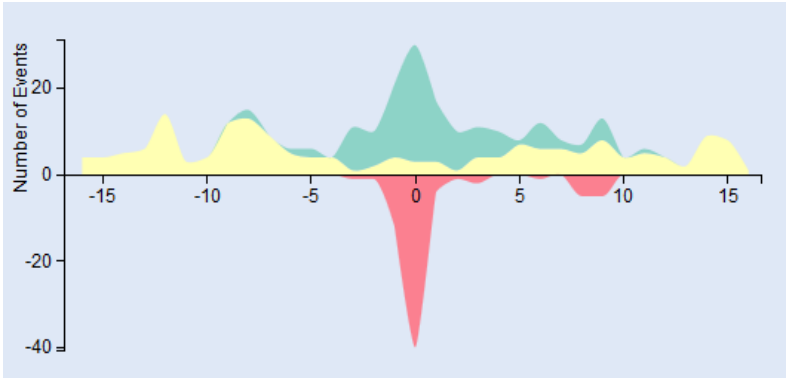

Figure: Neutral-Negative

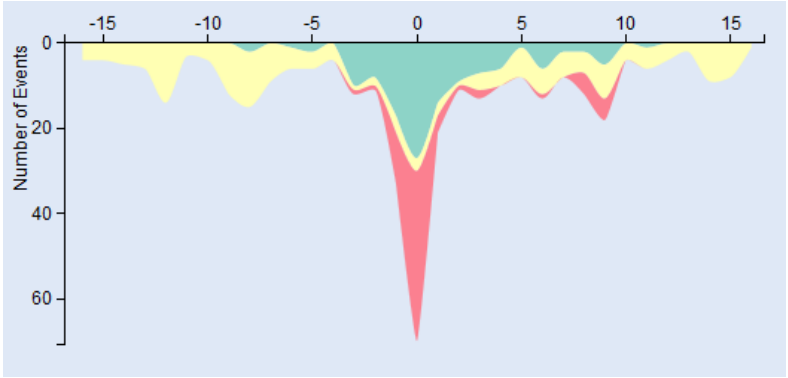

Figure: Positive

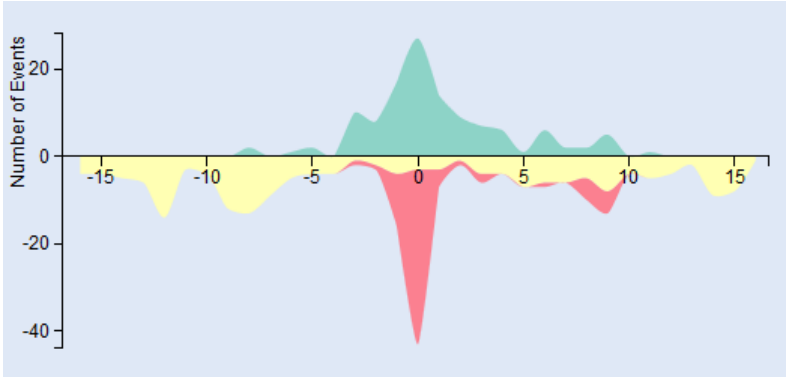

Figure: Positive-Neutral

Session Visualization - Heatmap (T1.2)

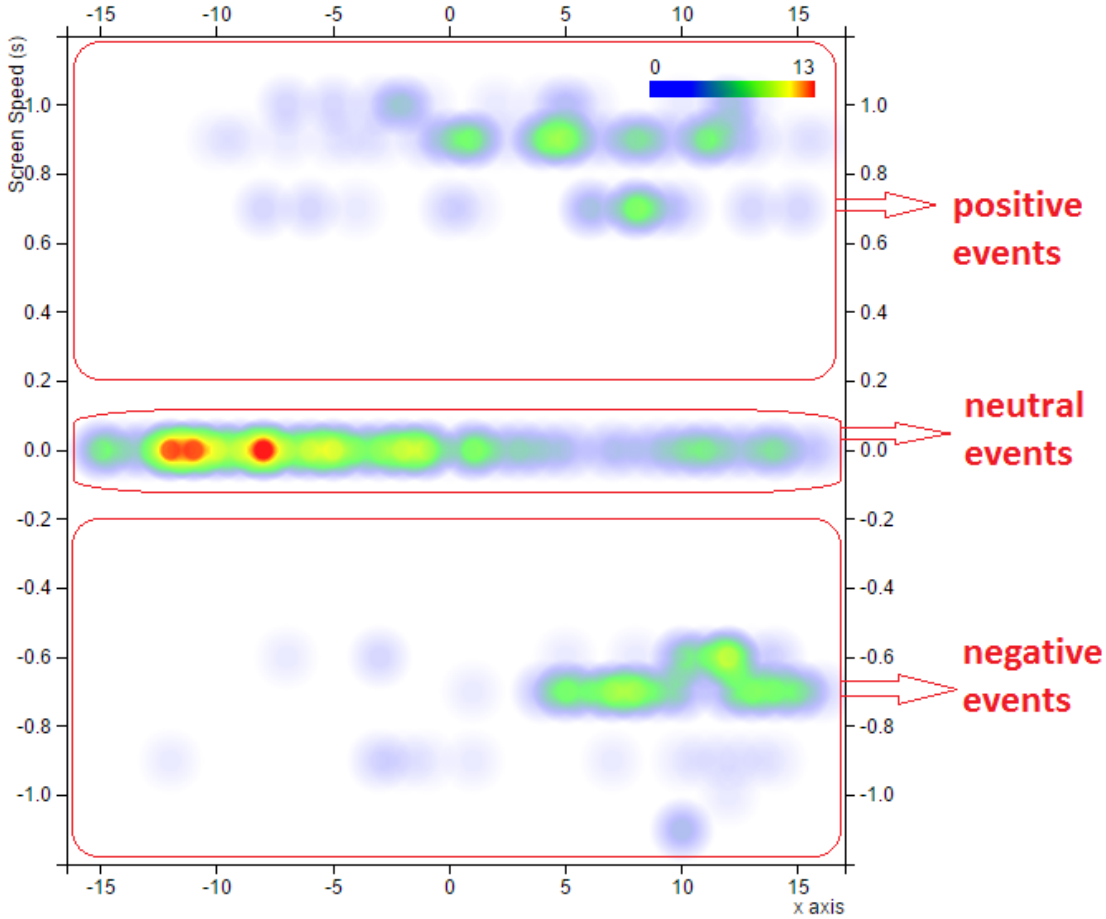

Figure: Heatmap depicting number of events and screen speed over x axis

Summary Visualization by range of x-area (T2.1)

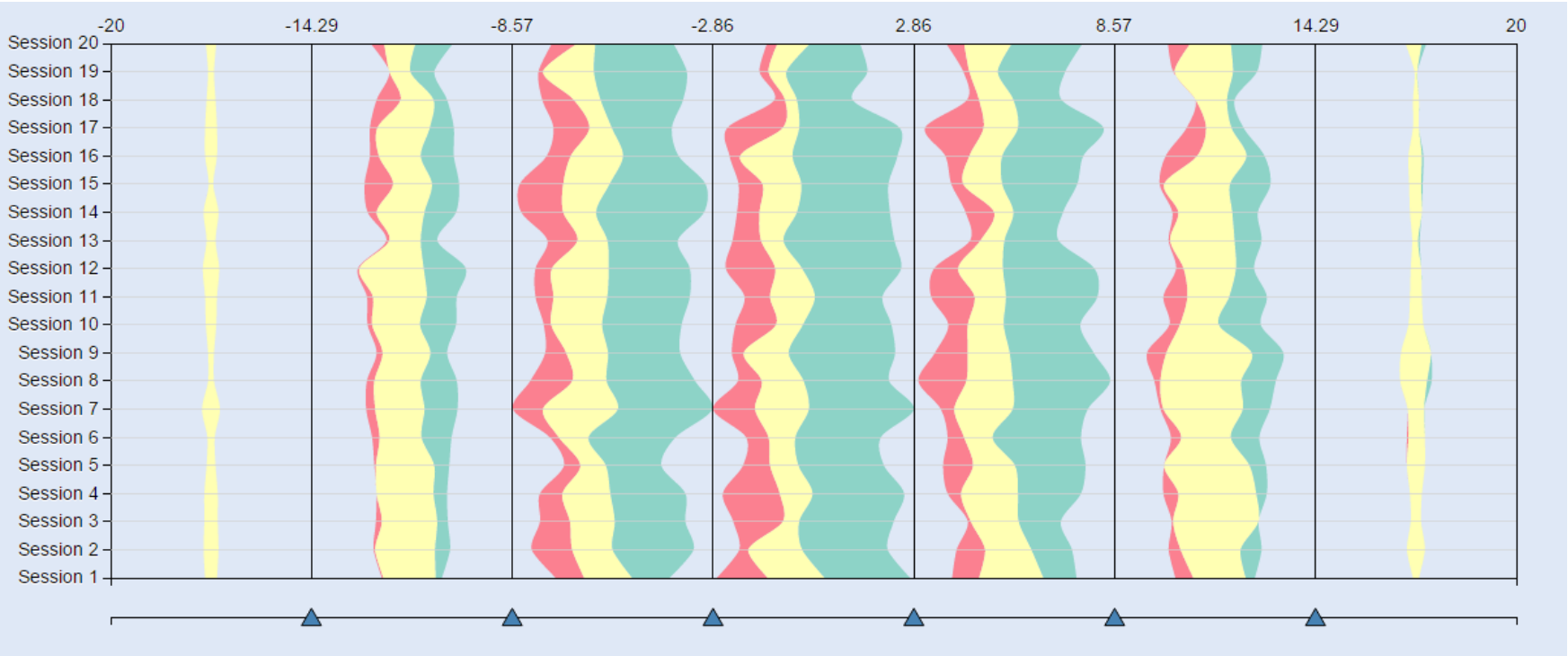

Figure: Summary Visualization by range of x-area: each section has the same x-range

Summary Visualization by number of events (T2.3)

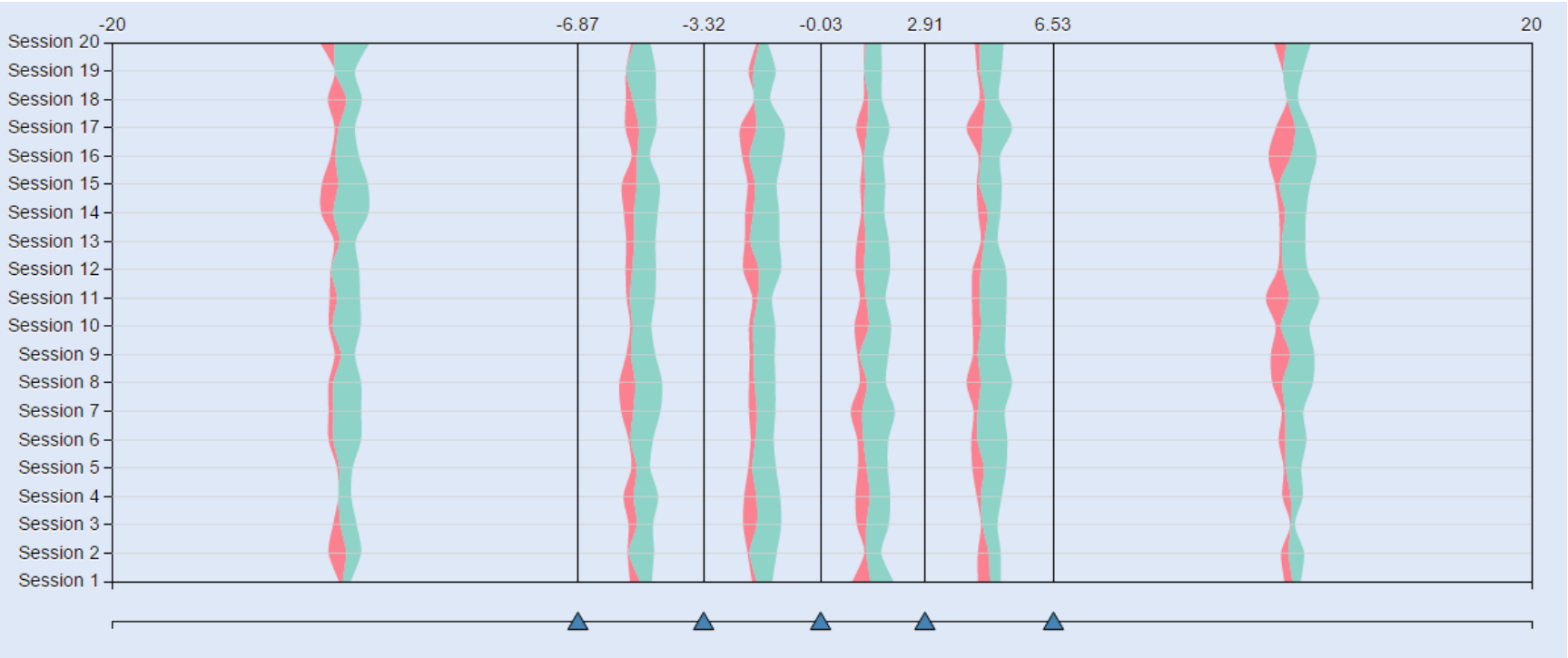

Figure: Summary Visualization by number of events: each section has the same number of positive and negative events

Summary Visualization by clustering (T2.5)

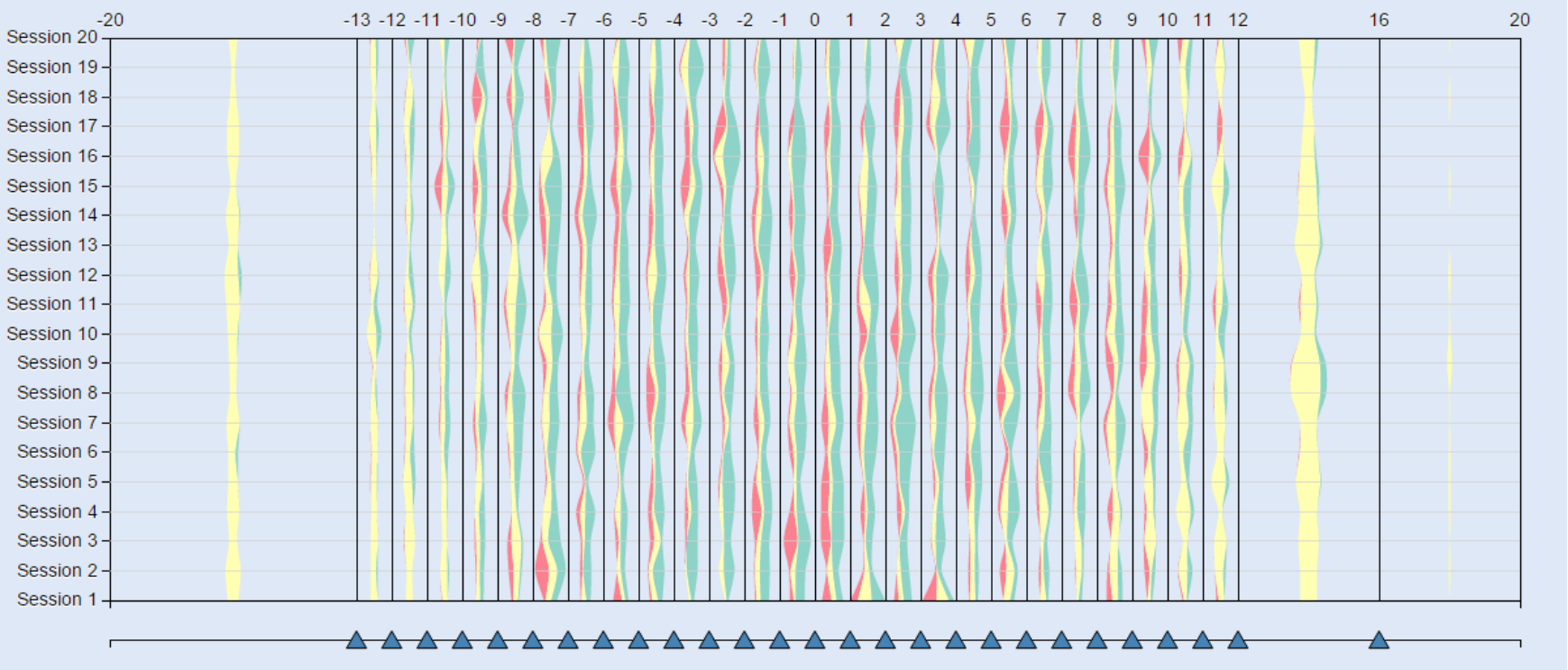

Figure: Summary Visualization by clustering: each section has the similar movement pattern

Summary Visualization - Interaction Technique(T2.2,T2.4)

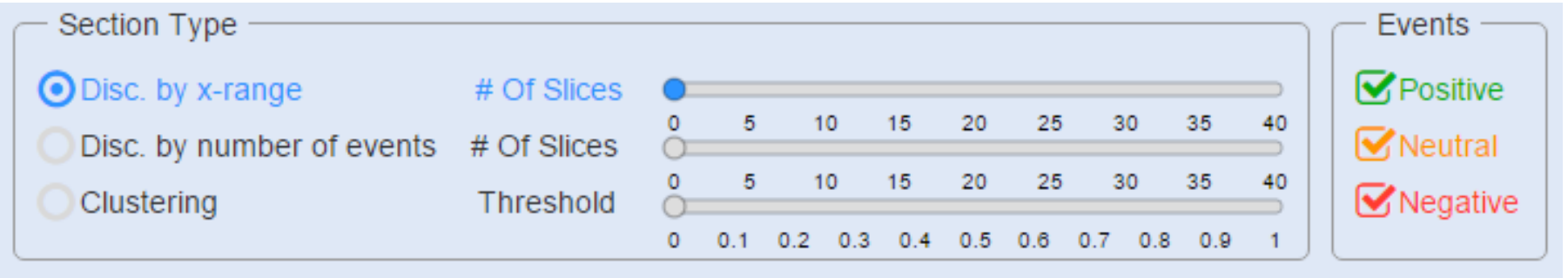

Figure: Interaction bar allows user to choose which event type to show and change input using sliders

Summary Visualization - Interaction Technique

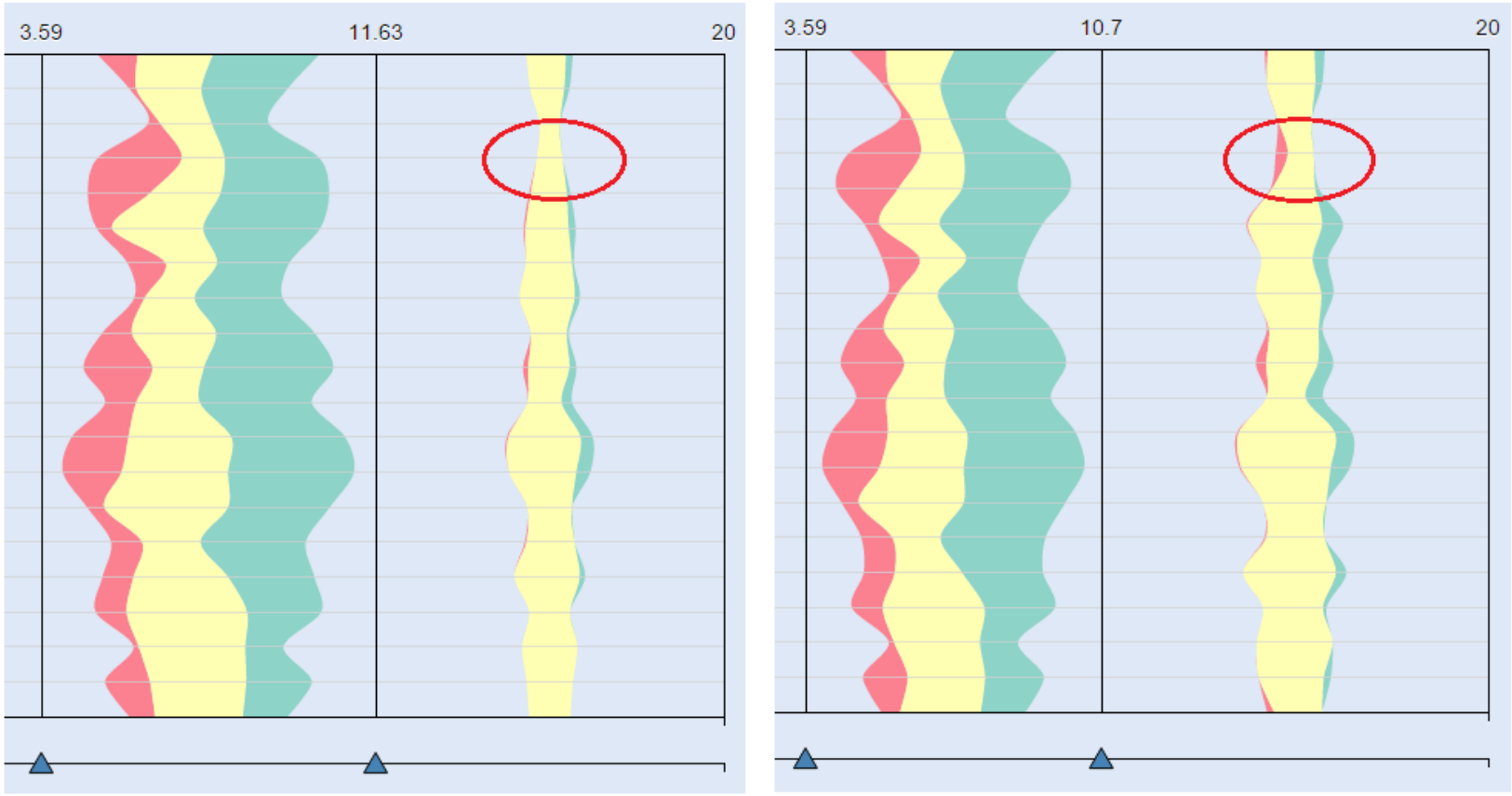

Figure: By dragging section line or triangle symbol, user can highlight movement pattern

General Interface

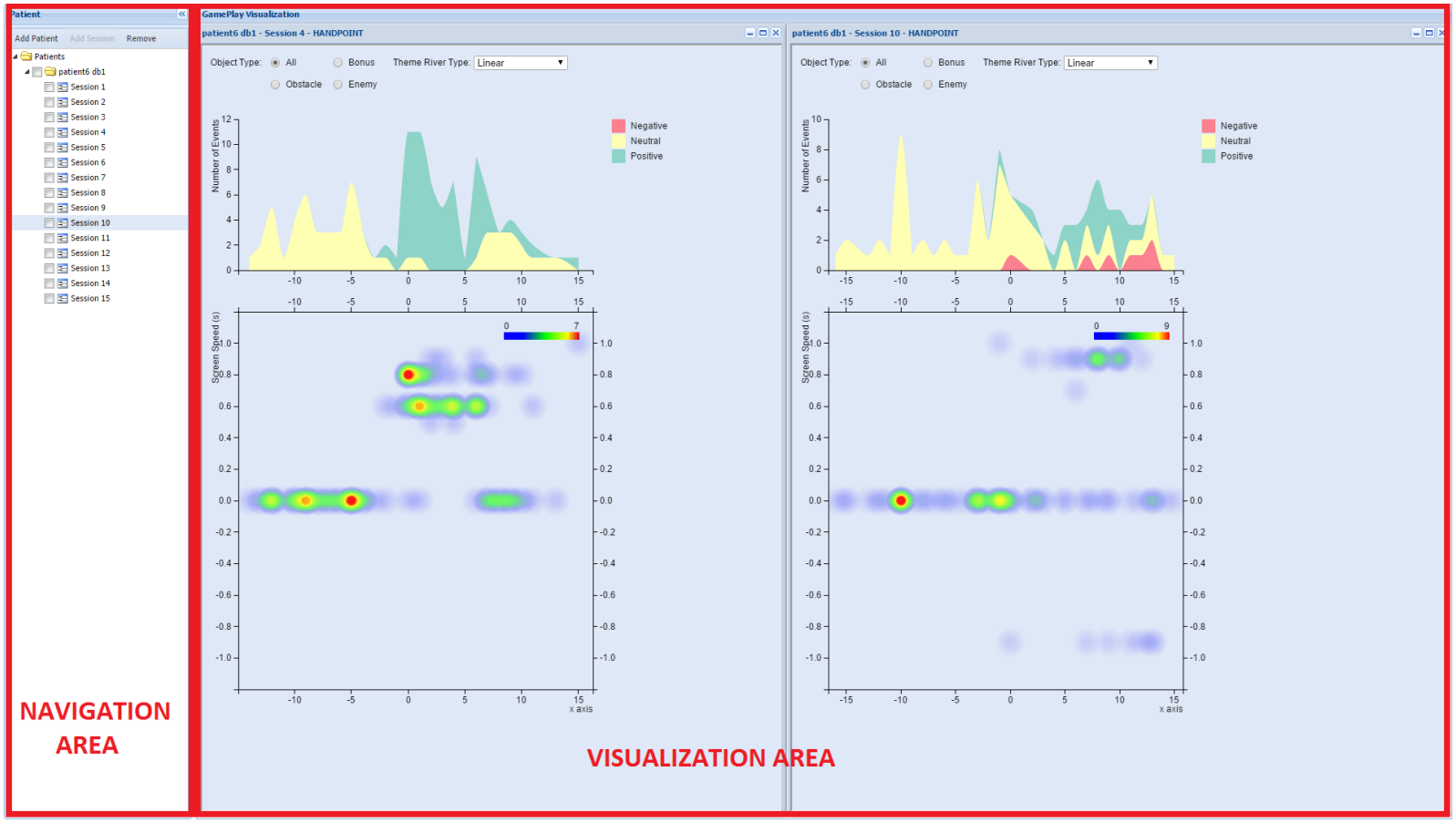

Figure: Interface is divided into two areas: navigation area and visualization area

Case Study and Demo

- Data set is acquired from NaturalPad
- Data set is of game played by patient with pathology(type of pathology unknown)
- Case study using HandPoint exercise, consists of 6 sessions

Conclusion

- The proposed visualizations are able to provide information on movement direction, movement and its related events, movement evolution
- Case study shows the effectiveness of the interface in achieving the tasks defined
- Future Works:
  - Improve clustering using different distance measure
  - Study on pathology and its movement to propose game setting based on pathology and its severity
  - Visualize log data related to skeleton movement