Interactive Visual Analysis of Ethological Studies: Getting Insight from Large Animals' Paths Ensembles

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Abstract

In this paper we describe how interactive visual analysis can be efficiently used to analyze a large ensemble of animal paths. Behavioral studies of animals are carried out in order to gain new insight in animal behavior, influence of drugs and various physiological processes. We illustrate how a coordinated multiple views system can complement conventional analysis and enable new insights in complex data. The newly proposed methodology is being tested with domain experts from University of Veterinary Medicine, and first feedback is very positive. Several illustrative examples based on data from more than 800 observations are presented.

1. Introduction

Behavioral studies of animals are carried out daily to comprehend neural mechanisms underlying learning process, various physiological processes and the influence of drugs and medical interventions on animals [BLJ94, HES*06, WPF09, LWF11]. A better understanding of the behavioral patterns of animals leads to a better understanding of similar processes for humans and, consequently, to better medical care. Animal experiments are carried out only in strict accordance with the law and ethical approaches.

There are various types of ethological studies. In this paper we deal with behavioral monitoring of animals in an Open Field (OF) with an Object Placement Task (OPT). We illustrate how interactive visual analysis can help domain experts to better understand the data and to comprehend large ensembles of observations. The same approach can be used for various types of fields (Barnes Maze, (multiple) T-Maze, etc.). The standard procedure is to track each animal using a video tracking system, and to compute various parameters

for each observation. Most of the tracking software available can compute the total distance an animal completed in a given time, average speed, time spent in certain field areas, number of field crossings, etc. Once all observations are done, statistical analysis of all parameters is carried out. The complete analysis is solely done based on the parameters computed from animal paths without taking into account the original path of the animal.

No system, according to our best knowledge, uses paths of multiple observations in analysis in order to link various parameters and show up context of behavioral characteristics. In this system paper we describe how we extended a standard approach by means of interactive visual analysis. The newly proposed methodology complements conventional statistics and makes an in-depth analysis possible. Many features simple not covered by parameters can be examined in detail, and domain experts can gain additional knowledge. We have combined the TiBe 1.0 monitoring tool [Wei08] and ComVis [MFGH08], a coordinated multiple views tool, to create a powerful system for the analysis of animal behavioral observation ensembles. We will illustrate the proposed approach on a collection of more than 800 observations. The development of the methodology has been done in a close collaboration with domain experts who coauthor this paper. First impressions and results are very promising and the collaboration is still ongoing.

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2. Related Work

Visual analytics [KKS*11] is "the science of analytical reasoning facilitated by visual interactive interfaces" [TC05]. Interaction techniques allow the user to better understand the data due to the ability to interact with the data and receive immediate visual feedback. The visual analysis of large, high-dimensional, and time-dependent data sets is supported by well established techniques, such as Focus+Context (F+C) visualization [Hau06]. Focus+Context visualization is often used in a coordinated multiple views (CMV) [Rob07] setup that also supports linking and brushing [MFGH08]. In our previous work [KMG*06] we described the curve view. We used it for interactive visual analysis of various complex data containing families of curves [MGKH09, MLK*08, TMS*08].

Andrienko et al. [AAW07] describe a framework for analysis of movement data combining interactive visual displays, cognition, and reasoning with database operations and computational methods. They focus on large scale movements and do not have many parameters of objects being observed. Scheepens et al. use density maps [SWvd-WvW11, SWvdW*11] to analyze multivariate trajectories of vessels. Bak et al. introduced growth ring maps for the spatiotemporal analysis of sensor logs of mice [BMJK09]. Several authors analyze flow pathlines using interactive visual analysis and pathlines' parameters [LZM*11, STH*07].

Both, the open field, as well as the OPT, are well described tests which are highly applicable for various approaches in behavioral research [WKF08, HPH*09, FW10, VGAC11]. Although the testing methods and the setup of the test battery are similar in both tests, the range of memory tested differs: in the OF locomotor activity, exploratory and anxiety related behavior is evaluated, while the OPT is concerned with spatial reference memory.

Hoeger et al. [HPH*09] evaluated exploratory behavior in mice transgenic for reduced folate carrier by using the OF. Parameters were evaluated with TiBe 1.0 [Wei08], center crossings were found increased in the OF, indicating modulated anxiety-related behavior. Bubna-Littitz and Jahn [BLJ94] could verify age-declining motor activity in the OF with rats. Another study about aged-related stimulatory deprivation in rats demonstrated, that cognitive stimulation is able to counteract the age-related decline in memory and learning. These cognitive stimulation was given amongst others also by performing an OPT tracked with TiBe 1.0 [Wei08]. Walf et al. [WKF08] tested spatial memory in the OPT in estradiol treated mice, finding enhanced performance in the hormone treated group compared to the control group with estradiol receptor knockout mice.

3. Data Model and Proposed Approach

As stated above we have used TiBe 1.0 for data acquisition. The TiBe tool can record the trajectories of mice/rats and
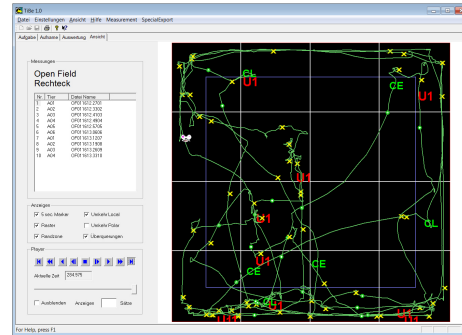

Figure 1: *A screenshot from the evaluation module of TiBe 1.0. The path for single measurement is shown (it can be animated). Virtual raster of the field, border area limit, and important events are also shown. This view is used to check a single path at a time and it is not used in numerical analysis.*

computes all necessary parameters. Various settings for parameter computation can be set by the user. The TiBe tool offers a measurement display mode, where the user can examine one measurement (Figure 1). The TiBe tool is regularly used at the University of Veterinary Medicine, Vienna. We have collected 814 measurements of an Object Placement Task (OPT). The OPT is a test for assessing spatial reference memory. Therefore, the animal is placed in an OF (120x120cm) with two identical objects and allowed to explore them for 5 minutes. In a second session, one object is still at the same location, but the other object got displaced. The time spent exploring the displaced object is measured and compared to the total amount of time spent exploring both objects. In the OF test is used for evaluating exploratory behavior, locomotor activity and anxiety-related behavior in rodents. The monitoring tool tracks the animal in real-time (8 Hz) and saves the position information. When the whole tracking session is over, the path parameters are computed and the data is exported for statistical analysis. Each measurement corresponds to on record.

In order to allow for an in-depth analysis we propose to use animal paths throughout the whole analysis process. We apply a data model proposed by Konyha et al. [KMG*06] which allows curves as single attributes in records. This means that in our multivariate multidimensional data each record contains various animal parameters (ID, age,...), various animal path parameters (total path length, average animal speed, percentage of time spent near border, number of field crossings, ...), and the path itself. Besides the path we also computed the distance traveled as a function of time.

We use a coordinated multiple view system to analyze the complex data. The system supports various standard views (scatter-plot, histogram, parallel coordinates, e.g.), and the path view to depict animal paths. We depict all paths at once using density mapping in order to identify areas where more
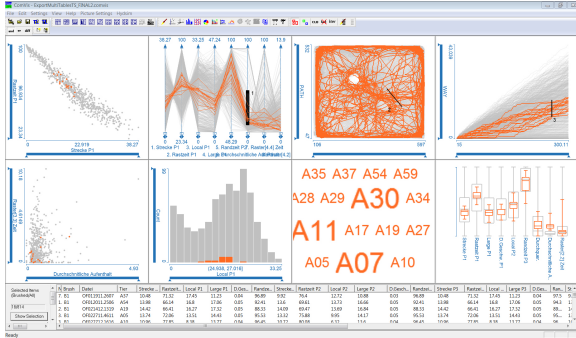
Figure 2: *A screenshot from an analysis session using CMV. The domain expert uses scatterplot, parallel coordinates, path view, and traveled distance view (top row), as well as scatterplot, histogram, tag cloud for animal IDs and box plot view (bottom row) simultaneously. She brushes features of interest and sees the corresponding records in all views. The box plot view shows all relevant statistical values.*
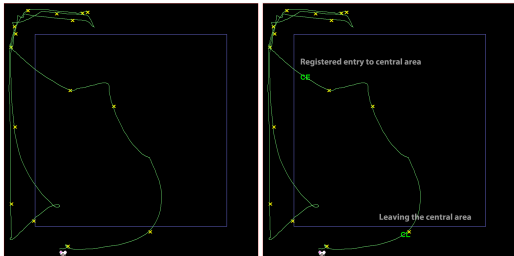

Figure 3: *The same path (first 70 seconds of an actual path are shown) is evaluated with different crossing angle parameters. The crossing of the central area is detected on the right and not detected on the left. Inspection of all runs one by one is tedious, and the newly proposed system makes the setting of parameters much more efficient.*

paths are overlapping. Composite brushing makes it possible to select subsets of data. A line brush [KMG∗06] can be used in the path view. The user simply draws a line and all paths that cross that line are selected. More brushes can be combined using Boolean operations and support very efficient drill down of data. Figure 2 shows a screenshot from analysis using the ComVis tool. We use a box-plot view integrated in the CMV to get an overview of all available statistical measures. Other values, like correlations, are also available and can be depicted using other views.

4. Illustrative Examples

We were interested in several tasks when we started the analysis. First, we wanted to check if the evaluation parameter settings are correct. For example, the user defines the width of the border area, or angles that define if the field is crossed

or not. These are empirical values and we used the new system to evaluate such user set parameters. We simply varied the parameters and checked which give the correct results. In case of field crossing, it is clear that we assume that the field is crossed if the animal enters the central area on one side and subsequently leaves on the opposite side. But is it a crossing if it leaves the central area on a neighboring side? We were able to tune the parameters for multiple runs, and to decide on correct evaluation parameters using the newly proposed approach. Figure 3 shows one animal path evaluated with different field crossing settings. Although the animal does not leave the central area on the opposite side we should consider it as a crossing.

Once the evaluation parameters are properly set we can focus on the analysis of the results themselves. In our case we have more than 800 measurements and for each of them the aggregated values are computed first. The conventional analysis, which is currently the state of the art in the field, computes then everything based on the these aggregated values. For each path values like length, number of central area crossings etc. are computed, and a statistical analysis is performed. We want to see if there are some interesting patterns in the paths themselves. We will then use the path view, where all paths are depicted at once, and the traveled distance view. The traveled distance is a monotonically increasing function which represents the traveled distance as a function of time. We depict all distances at once in a curve view (Figure 4). We will start our exploration using this view.

First we can see that some animals travel 43 meters during the observation time (5 minutes) , and some practically did not move at all. There are many reasons why some animals move more and some less, and the researchers use it as an indicator for numerous issues. If we simply brush animals who traveled at least 35 meters (Figure 4b) we can see that they were constantly moving. We move the brush now to see the traveled distances of animals who traveled about 20 meters (Figure 4c). Interestingly we see some animals who had traveled only a short distance in a long time (Figure 4d) and then started moving. We can simply brush them using another brush and the logical 'and'-operation. If we move the second brush now, we will see the opposite case, active at the beginning followed by low activity (Figure 4e).

Finally, we explored animals which traveled a distance of less than 5.5 meters. We brush the corresponding bins in the total distance histogram (Figure 5a histogram on the left) and see the corresponding traveled distances and paths. If we select only very short distances, less than 0.8 meters, we see that those animals spend all the time in corners (Figure 5b). If we select high values we see that those few animals cross the field. Interestingly, the two selected animals have exactly the opposite behavior, one is quite stationary for a long time and then crosses the field, and anther one crosses the field very early and then stays stationary. Another interesting case for our domain experts which needs further examination.
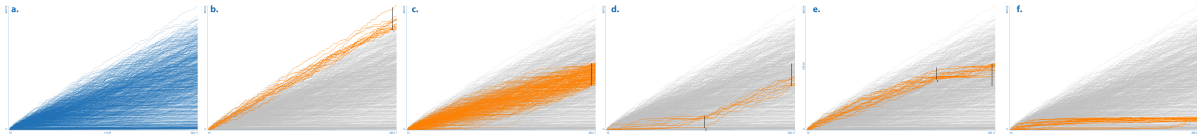
Figure 4: *a. Traveled distances as function of time for all animals. b. Animals with the largest total traveled distance are selected (> 35 meters). They are constantly moving and their traveled distance constantly increases. c. For distances of about 20 meters, there are three patterns - constant move (with slower speed than animals brushed in b.), rest first then move (brushed in d.), and move first then rest (brushed in e.). f. For animals which traveled just a short distance, there are two patterns visible (rest then move, move then rest).*

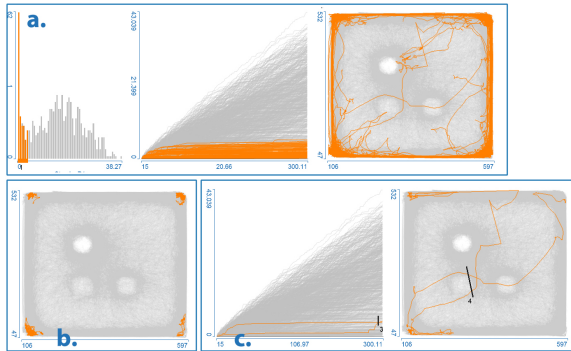**Figure 5:** *We examined animals which traveled less than 5.5 meters in detail. a. Brush corresponding bins in histogram. b. Refine selection to lowest values only (brush not visible) – animals stay in corners. c. Highest values and field crossing – two patterns again.*

Figure 6: *a. All paths depicted in path view. Note one spot where no animal passed, and two spots where some of them passed, due to object shifting in the Object Placement Task (OPT). Note also high path density close to the border. b. Animals that crossed the right spot didn't cross left spot (object was there). There are about 100 paths that crossed each spot.*

Besides traveled distance, we can also analyze the paths themselves. When we first showed all paths at once, an interesting pattern occurred. There is a white spot where no animal passed through, and two spots where not many animals passed through (Figure 6a). There could be several reasons. It can be a smell of something at this spot which distracts the animals. In our case, these spots mark the objects of the Object Placement Task (OPT). The rather white spot is the object, which was at the same place in both trials, whereas the other 2 spots were emerging from the displaced object. By shifting it from one place to the other in the second trial, the animal was able to walk an the area formerly blocked by the object. Hence tracks appear in 2 of the three spots. If we brush the tracks crossing one spot we see that those tracks do not cross the other spot (the object was there), and vice versa. Figure 6b shows this case. Interestingly, approximately 100 paths crossed each spot. We can also easily brush the paths around each spot and immediately see all parameters associated with those paths.

The illustrative examples described above would not be possible using the conventional approach. Once interesting patterns are identif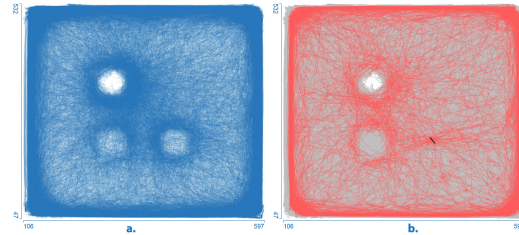ied by using the interactive system, the researchers have to study the causes for such behaviors. Future observations could prove the influence of all kinds of animal senses, for instance by visualization of certain OF-areas (preferred or omitted). The linked views, where they can immediately see all corresponding parameters, support them in the discovery process. The total traveled distance, used in current state of the art tools, is simply not sufficient for such a detailed analysis.

5. Conclusions

In this paper we present a novel analysis method for analysis of animal behavioral studies data. Interactive visual analysis in conjunction with a complex data model complement conventional analysis methods and enable researchers to get new insights. The inclusion of animal paths in the analysis process is only possible in an interactive setup. Coordinated multiple views and advanced brushing enable an interactive drill down process. Complete statistical analysis is available all the time, and researchers can easily check newly generated hypothesis. The newly introduced system got very positive feedback from domain experts and we are currently performing a more extensive analysis. We expect to further improve the system and to find explanations for many new discoveries.

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